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Vol. XXVI. AUGUST, 1900. No. 6.

PROCEEDINGS

OF THE

AMERICAN SOCIETY OF CIVIL ENGINEERS.

Edited by the Secretary, under the direction of the Committee on Publications.

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The prices of publications are as follows: *Proceedings*, $6 per annum; *Transactions*, $10 per annum. Postage will be added when *Proceedings* are sent to foreign countries.

American Society of Civil Engineers.

OFFICERS FOR 1900.

President, JOHN FINDLEY WALLACE.

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Term expires January, 1901:	*Term expires January, 1902:*
ROBERT CARTWRIGHT.	RUDOLPH HERING,
ROBERT MOORE.	ALFRED NOBLE.

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Treasurer, JOSEPH M. KNAP.

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Term expires January, 1901:	*Term expires January, 1902:*	*Term expires January, 1903:*
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Special Committees.

On Analysis of Iron and Steel:—Sub-Committee of the American Society of Civil Engineers (of the International Committee on Standards for the Analysis of Iron and Steel, of which Prof. J. W. Langley is Chairman)—Charles B. Dudley, William Metcalf, Thomas Rodd.

On Units of Measurement:—George M. Bond, William M. Black, R. E. McMath, Charles B. Dudley, Alexander C. Humphreys.

On the Proper Manipulation of Tests of Cement:—George F. Swain, Alfred Noble, George S. Webster, W. B. W. Howe, Louis C. Sabin, H. W. York.

◆

The House of the Society is open every day, except Sunday, from 9 A.M. to 10 P.M.

House of the Society—220 West Fifty-seventh Street, New York.

Telephone Number, - - 533 Columbus.
Cable Address, - "Ceas, New York."

Vol. XXVI. AUGUST, 1900. No. 6.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PROCEEDINGS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

SOCIETY AFFAIRS.

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MINUTES OF MEETINGS.

OF THE SOCIETY.

June 6th, 1900.—The meeting was called to order at 8.50 P. M., Vice-President Robert Cartwright in the chair; Charles Warren Hunt, Secretary, and present, also, 95 members and 18 guests.

The minutes of the meetings of May 2d and 16th, 1900, as printed in *Proceedings* for May, 1900, were approved.

A paper entitled "A Proposed Method for the Preservation of Timber," by F. A. Kummer, Jun. Am. Soc. C. E., was presented by the author.

The subject was discussed by Messrs. H. G. Prout, J. H. Deghuée, Robert Cartwright, O. F. Nichols, F. W. Skinner, Henry Goldmark and the author.

Ballots were canvassed and the following candidates declared elected:

As Members.

Edward Marshall Boggs, Los Angeles, Cal.
Godfrey Pearson Farley, Wiscasset, Maine.
Stanley Wolcott Hayes, Buffalo, N. Y.
James Clark Irwin, Albany, N. Y.
Richard Lamb, New York City.
Edward Hervey Lee, Chicago, Ill.
Edwin Kirtland Morse, Pittsburg, Pa.
Frank Thompson Oakley, Toledo, Ohio.
Harry Elstner Talbott, Michipicoten Harbor, Ont.

As Associate Members.

Ellis Alexander Frink, Baltimore, Md.
Martin Hughes Gerry, Jr., Canyon Ferry, Mont.
Nathaniel Oliver Goldsmith, Cincinnati, Ohio.
John James Herrick, Flushing, N. Y.
Alfred Courtney Lewerenz, New London, Conn.
Van Norman McGee, Tientsin, China.
Gerard Hendrik Matthes, Washington, D. C.
William Nelson, Laconia, N. H.
Philip Morris Pritchard, Liverpool, Eng.
William Jackson Roberts, Pullman, Wash.
Charles Davis Vail, Butte, Mont.
Henry Arthur Van Alstyne, Albany, N. Y.

The Secretary announced that the following candidates were elected by the Board of Direction, June 5th, 1900:

As Associates.

Howard Elliott, St. Louis, Mo.
Alexander Ross Piper, Sing Sing, N. Y.

As Juniors.

Henry Robinson Buck, Wethersfield, Conn.
Frederic Francis Hall, Riverside, Cal.
Charles Frederic Parker, Durango, Mexico.
Frederick William Schwiers, New York City.

The Secretary announced the death of the following Members: Norman Wilder Eayrs, elected Member June 3d, 1885; died May 13th, 1900. Marc John Reiseger, elected Member December 7th, 1898; died May 26th, 1900. Bentley Douglas Hasell, elected Member July 3d, 1878; died May 29th, 1900.

Adjourned.

THIRTY-SECOND ANNUAL CONVENTION, HELD IN LONDON, ENGLAND.

In response to the invitation of the Institution of Civil Engineers, the Thirty-second Annual Convention of the Society was held at the House of the Institution, Great George St., Westminster, S. W., London, England, during the first week in July, 1900.

Monday, July 2d, 1900.—*Sir* Douglas Fox, President, Inst. C. E., addressed the American engineers, assembled in the Library of the Institution. John F. Wallace, President, Am. Soc. C. E., briefly responded and introduced H. S. Haines, M. Am. Soc. C. E., who responded for the Society. Mr. Jesse M. Smith spoke for the American Society of Mechanical Engineers.

First Session, Monday, July 2d, 1900.—The opening meeting was held in the afternoon; President John F. Wallace in the chair; Charles Warren Hunt, Secretary.

The President delivered the Annual Address.

On motion by *Sir* Douglas Fox, Cor. M. Am. Soc. C. E., seconded by Desmond FitzGerald, Past-President, Am. Soc. C. E., a vote of thanks to the President for his Address was unanimously passed.

Adjourned.

Second Session, Monday, July 2d, 1900.—The Society was called to order at 8 P. M.; President John F. Wallace in the chair; Charles Warren Hunt, Secretary.

The President announced the subject for discussion, as follows:

"The Height of Buildings: What considerations should limit the height of buildings? Do recent developments in construction, sanitation, intercommunication and economy of administration, warrant the removal of all restrictions?"

The Secretary presented a discussion by CORYDON T. PURDY, M. Am. Soc. C. E., illustrated by lantern slides.

The Secretary also presented a written discussion by REGINALD PELHAM BOLTON, M. Am. Soc. C. E.

The subject was further discussed by:

R. W. HUNT, M. Am. Soc. C. E.
Sir ALEXANDER BINNIE, M. Inst. C. E., Chief Engineer, London County Council.
W. E. RILEY, M. Inst. C. E., Architect, London County Council.
H. DE B. PARSONS, M. Am. Soc. C. E.
R. J. GIFFORD READ, Assoc. M. Inst. C. E.
O. J. KIRBY, Assoc. M. Inst. C. E.
JOHN F. WALLACE, President, Am. Soc., C. E.

Adjourned.

Third Session, Tuesday, July 3d, 1900.—The meeting was called to order at 10 A. M.; President John F. Wallace in the chair; Charles Warren Hunt, Secretary.

The President announced the subject for discussion, as follows:

"Recent Practice in Rails: The progressive increase in weight; the increase in hardness, particularly in carbon; the sections in most general use; the effect of changes in weight, composition and section."

The subject was introduced by ROBERT W. HUNT, M. Am. Soc. C. E., who was followed by:

A. L. COLBY, M. Am. Soc. Mech. Eng.
WILLIAM R. WEBSTER, M. Am. Soc. C. E.
Sir LOWTHIAN BELL, M. Inst. C. E.
J. D. SMELT, M. Inst. C. E., Engineer, Argentine Great Western Ry.
JOHN F. WALLACE, President, Am. Soc. C. E.

The President announced the next subject for discussion, as follows:

"Filtration of Water for Public Use: The several processes now used for the removal of objectionable matter; their comparative sanitary effect, cost and reliability."

The subject was introduced by RUDOLPH HERING, Vice-President, Am. Soc. C. E., who was followed by:

W. H. LINDLEY, M. Inst. C. E.

Further discussion on this subject was postponed until Thursday, July 5th, 1900.

Adjourned.

Fourth Session.—At the close of the Business Meeting, Thursday, July 5th, 1900.—Vice-President Hering in the chair; Charles Warren Hunt, Secretary.

The chair announced the resumption of the discussion on "Filtration of Water for Public Use."

The following gentlemen presented their views:

GEORGE F. DEACON, M. Inst. C. E.
GEORGE W. FULLER, M. Am. Soc. C. E.
DR. SAMUEL RIDEAL, London.
HENRY DAVEY, M. Inst. C. E.
DR. AD. KEMNA, Antwerp.
K. E. HILGARD, M. Am. Soc. C. E.
WALTER HUNTER, M. Inst. C. E.
J. N. GREENE, M. Am. Soc. C. E.
ANDREW JOHNSTON, M. Inst. C. E.

Adjourned.

BUSINESS MEETING.*

Thursday, July 5th, 1900.—The meeting was called to order at 10 A. M.; President John F. Wallace in the chair; Charles Warren Hunt, Secretary.

The reading of the minutes of the meeting of June 6th, 1900, was dispensed with.

The Secretary reported the result of the interrogatory circular relating to nominations for Members of the Nominating Committee, the report of each district being given separately.

The following members were elected by the meeting:

NELSON P. LEWIS............	*Representing*	*District*	*No.*	*1.*
FREDERIC P. STEARNS........	"	"	"	*2.*
EDWARD B. GUTHRIE.........	"	"	"	*3.*
EDGAR MARBURG.............	"	"	"	*4.*
CHARLES L. STROBEL.........	"	"	"	*5.*
EDWARD FLAD...............	"	"	"	*6.*
A. J. TULLOCK..............	"	"	"	*7.*

The Secretary reported' the result of an interrogatory circular issued to secure the views of the membership as to the time and place for holding the Annual Convention of 1901.

On motion, the matter was referred to the Board of Direction, with power.

J. A. Ockerson, M. Am. Soc. C. E., presented a request from the members resident in St. Louis, Mo., that the Annual Convention of 1903 be held in that city, during the proposed World's Fair.

On motion, the matter was referred to the Board of Direction.

The following proposed Amendment to the Constitution was considered:

Amend Article VII, as follows:

SECTION 2. * * * Strike out this section and substitute the following:

"2.—At the Annual Meeting of each year, seven Corporate Members, not officers of the Society, one from each of the geographical districts, shall be appointed by the meeting to serve for two years; who, with the five living last Past-Presidents of the Society, shall be a committee to nominate officers for the Society.

"The Board of Direction may prescribe the mode of procedure for appoining this Committee.

"The Committee so appointed shall meet at the Annual Convention of the Society, and nominate candidates to fill the offices, named in Article V, so as to provide, with the officers holding over, a Vice-President and six Directors residing in District No. 1, and twelve Directors divided equally, with regard to number and residence, among the remaining districts, Nos. 2, 3, 4, 5, 6 and 7.

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*The report in full will be published in a later number of *Proceedings*.

"A list of nominees for the offices to be filled at the next Annual Election shall be presented by the Committee to the Board of Direction within ten days after the nominees have been selected."

The proposed amendment was not amended by the meeting.

J. A. Ockerson, M. Am. Soc. C. E., moved the following:

"*Resolved,* That the American Society of Civil Engineers, in Convention assembled, sends its cordial greeting to the Société des Ingénieurs Civils de France, and expresses its hearty thanks for the warm reception accorded to its delegates in Paris."

The resolution was carried unanimously.

Rudolph Hering, Vice-President, Am. Soc. C. E., moved that the President be requested to appoint a Committee to draft appropriate resolutions of thanks to the Institution of Civil Engineers and to the various other corporations that have so generously entertained our members at this Convention.

The motion was adopted unanimously.

The meeting then adjourned.

OF THE BOARD OF DIRECTION.

(Abstract.)

June 5th, 1900.—The Board met at 8.10 P. M., Vice-President Alfred Noble in the chair; Charles Warren Hunt, Secretary, and present also Messrs. Cartwright, Deyo, Knap, Morison, O'Rourke, Ricketts, Schneider, Turner and Whinery.

The President was authorized to appoint delegates from the Society to represent it at the Eighth International Congress on Navigation, to be held in Paris.

The President, in response to an invitation from the President of the Société des Ingénieurs Civils de France, appointed seven delegates to represent the Society at the Reunion of Scientific and Technical Societies.

It was resolved that the next meeting of the Board be held on September 11th, instead of September 4th, 1900.

Applications were considered and other routine business transacted.

Two candidates for Associate and four for Junior were elected.

Adjourned.

July 5th, 1900.—A meeting of the Board of Direction was held, as required by the Constitution. President John F. Wallace in the chair; Charles Warren Hunt, Secretary, and present, also, Vice-President Rudolph Hering.

A quorum not being present, the meeting adjourned.

EXCURSIONS AND ENTERTAINMENTS, DURING THE WEEK, BY THE INSTITUTION OF CIVIL ENGINEERS, AND PARTICIPATED IN BY MEMBERS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS.

Tuesday, July 3d, 1900.—The party left Paddington Station, by special train, at 2.50 P. M., arriving at Windsor Castle at 3.30 P. M.

The Castle and Grounds were then inspected, Her Majesty the Queen having graciously allowed the visit.

By direction of the Queen the party was served with refreshments in the Orangery, and later Her Majesty drove out to a point where the entire party was assembled, and Sir Douglas Fox, President of the Institution, was presented by Lord Edward Pelham-Clinton, Master of the Household. Sir Douglas Fox then presented to Her Majesty, Sir William Henry Preece, K. C. B., Past-President, Inst. C. E.; Mr. Charles Hawksley and Mr. Francis William Webb, Vice-Presidents; Mr. John F. Wallace, President, Am. Soc. C. E., and Mrs. Wallace; Mr. Charles H. Morgan, President, Am. Soc. Mech. Engrs., and Mrs. Morgan.

The return was made by special train, arriving in London at 6.45 P. M.

Thursday, July 5th, 1900.—9 P. M. There was held a Reception by the President and Council of the Institution, in the Ancient Guildhall (by special permission of the Corporation of London). This entertainment was magnificent in its proportions, 3 500 persons being present.

Friday, July 6th, 1900.—The day was devoted to an excursion to Warwick Castle and Stratford-on-Avon, by special train leaving Paddington Station at 10.05 A. M. The visitors were received by the Earl and Countess of Warwick, who personally conducted them through their beautiful Castle and Park. Luncheon was served in a marquee in the grounds. The special train then took the party to Stratford-on-Avon, where Shakespeare's House, Stratford Church and the Memorial Theatre were inspected. London was reached at 7.20 P. M.

ATTENDANCE AT THE THIRTY-SECOND ANNUAL CONVENTION.

The following 68 persons connected with the Society were in attendance, accompanied by 55 members of their families. The Society meetings were also attended by many members of the Institution of Civil Engineers, American Society of Mechanical Engineers and other visiting engineers.

Abbot, Fred. W......New York City

Baker, *Sir* Benjamin .London, Eng.
Baker, Ira O.........Champaign, Ill.
Bell, James R.........London, Eng.
Betts, E. E......Chattanooga, Tenn.
Booth, W. H..........London, Eng.
Braine, L. F........Brooklyn, N. Y.
Buck, L. L..........New York City

Cairns, R. A .....Waterbury, Conn.
Church, George E.....London, Eng.
Compton, A. G.......New York City
Crane, W. E.......Tarrytown, N. Y.

Davis, Arthur P..Washington, D. C.

Fisher, Clark.........Trenton, N. J.
FitzGerald, Desmond..Boston, Mass.
Flad, Edward.. .....St. Louis, Mo.
Fox, *Sir* Douglas.. ...London, Eng
Fuller, George W ....New York City
Furman, J. R.........London, Eng.

Gleim, C. O.....Hamburg, Germany
Goad, C. E......Toronto, Ont , Can.
Greene, J. N............Bangor, Me.
Griffin, P. H..........Buffalo, N. Y.

Haines, H. S.........New York City
Hardy, H............Southsea, Eng.
Hering, Rudolph.....New York City
Hilgard, K. E...Zurich, Switzerland
Hodgdon, Frank W....Boston, Mass.
Hunsiker, Millard.....London, Eng.
Hunt, Charles W.....New York City
Hunt, Robert W........Chicago, Ill.

Johnson, Lewis E .....Steelton, Pa.
Jones, Washington.Philadelphia, Pa.

King, Paul S.........New York City

Llewellyn, F. J..Minneapolis, Minn.

Manley, Henry........Boston, Mass.
Marburg, Edgar....Philadelphia, Pa.
Maxim, Hiram S......London, Eng.
Melvin, D. N...Linoleumville, N. Y.
Miller, Spencer.......New York City
Millis, John.....Willets Point, N. Y.
Moncrieff, J. M......Newcastle, Eng.

Ockerson, J. A........St. Louis, Mo.
O'Donnell, J. P... ...London, Eng.

Packard, R. G........New York City
Parsons, H. de B.....New York City
Perrilliat, Arsène..New Orleans, La.
Phipps, L. C..........Pittsburg, Pa.
Pontzen, E............Paris, France

Reynders, J. V. W..Harrisburg, Pa.
Robinson, A. W....Milwaukee, Wis.
Ruddle, John ...Mauch Chunk, Pa.
Ryder, E. M. T..New Haven, Conn.

Sawyer, Edward......Boston, Mass.
Scott, Addison M..Charleston, W.Va.
Smith, F. Hopkinson .New York City
Stauffer, D. McN.....New York City

Tait, J. G............New York City
Talbot, A. N............Urbana, Ill.
Thomson, John.......New York City

Van Sant, R. L ......St. Louis, Mo.

Wallace, John F........Chicago, Ill.
Warren, W. H.......Sydney, N.S.W.
Watson, Wm ....Boston, Mass.
Webster, William R.Philadelphia, Pa.
Wiley, William H....New York City
Woods, H. D. ..West Newton, Mass.

Yeatman, M. E........London, Eng.

ANNOUNCEMENTS.

In accordance with the resolution of the Board of Direction the House of the Society is open every day, except Sunday, from 9 A. M. to 10 P. M.

MEETINGS.

Wednesday, September 5th, 1900.—A regular business meeting will be held. Ballots for membership will be canvassed, and a paper by Elwood Mead, M. Am. Soc. C. E., entitled, "Irrigation Studies," will be presented for discussion. This paper was printed in the May number of *Proceedings*.

Wednesday, September 19th, 1900.—A regular meeting will be held, at which will be presented a paper by L. G. Montony, Assoc. M. Am. Soc. C. E., entitled "The Ninety-Sixth Street Power Station of the Metropolitan Street Railway Company, of New York City." This paper is printed in the current number of *Proceedings*.

MONTHLY LIST OF RECENT ENGINEERING ARTICLES OF INTEREST.

(May 9th to August 7th, 1900.)

NOTE.—*This list is published for the purpose of placing before the members of the Society the titles of current engineering articles, which can be referred to in any available engineering library, or can be procured by addressing the publication directly, the address and price being given wherever possible.*

LIST OF PUBLICATIONS.

In the subjoined list of articles references are given by the number prefixed to each journal in this list.

(1) *Journal*, Assoc. Eng. Soc., 257 South Fourth St., Philadelphia, Pa., 30c.
(2) *Proceedings*, Eng. Club of Phila., 1122 Girard St., Philadelphia, Pa.
(3) *Journal*, Franklin Inst., Philadelphia, Pa., 50c.
(4) *Journal*, Western Soc. of Eng., Monadnock Block, Chicago, Ill.
(5) *Transactions*, Can. Soc. C. E., Montreal, Que., Can.
(6) *School of Mines Quarterly*, Columbia Univ., New York City, 50c.
(7) *Technology Quarterly*, Mass. Inst. Tech.. Boston, Mass., 75c.
(8) *Stevens Institute Indicator*, Stevens Institute, Hoboken, N. J., 50c.
(9) *Engineering Magazine*, New York City, 30c.
(10) *Cassier's Magazine*, New York City, 25c.
(11) *Engineering* (London), W. H. Wiley, New York City, 35c.
(12) *The Engineer* (London), International News Co., New York City, 35c.
(13) *Engineering News*, New York City, 15c
(14) *The Engineering Record*, New York City, 12c
(15) *Railroad Gazette*, New York City, 10c.
(16) *Engineering and Mining Journal*, New York City, 15c.
(17) *Street Railway Journal*, New York City, 35c.
(18) *Railway and Engineering Review*, Chicago, Ill.
(19) *Scientific American Supplement*, New York City, 10c.
(20) *Iron Age*, New York City, 10c.
(21) *Railway Engineer*, London, England.
(22) *Iron and Coal Trades Review*, London, England.
(23) *Bulletin*, American Iron and Steel Assoc., Philadelphia, Pa.
(24) *American Gaslight Journal*, New York City, 10c.
(25) *American Engineer*, New York City, 20c.
(26) *Electrical Review*, London, England.
(27) *Electrical World and Electrical Engineer*, New York City, 10c.
(28) *Industries and Iron*, London, England.
(29) *Journal*, Society of Arts, London, England.
(30) *Annales des Travaux Publics de Belgique*, Brussels, Belgium.
(31) *Annales de l' Assoc. des Ing. Sortis des Ecôle Spéciales de Gand*, Brussels. Belgium.
(32) *Memoirs et Compt Rendu des Travaux*, Soc. Ing. Civ. de France, Paris, France.
(33) *Le Génie Civil*, Paris, France.
(34) *Portefeuille Economique des Machines*, Paris, France.
(35) *Nouvelles Annales de la Construction*, Paris, France.
(36) *La Revue Technique*, Paris, France.
(37) *Revue de Mecanique*, Paris, France.
(38) *Revue Générale des Chemins de Fer et des Tramways*, Paris, France.
(39) *Railway Master Mechanic*, Chicago, Ill.
(40) *Railway Age*, Chicago, Ill., 10c.
(41) *Modern Machinery*, Chicago, Ill.,, 10c.
(42) *Transactions*, Am. Inst. Elec. Eng., New York City, 50c.
(43) *Annales des Ponts et Chaussées*, Paris, France.
(44) *Journal*, Military Service Institution, Governor's Island, New York Harbor, 75c.
(45) *Mines and Minerals*, Scranton, Pa. 20c.
(46) *Scientific American*, New York City, 10c.
(47) *Mechanical Engineer*, Manchester, England.
(48) *Zeitschrift des Vereines Deutscher Ingenieure*, Berlin, Germany.
(49) *Zeitschrift für Bauwesen*, Berlin, Germany.
(50) *Stahl und Eisen*, Duesseldorf, Germany.
(51) *Deutsche Bauzeitung*, Berlin, Germany.
(52) *Rigasche Industrie-Zeitung*, Riga, Russia.
(53) *Zeitschrift des oesterreichischen Ingenieur und Architekten Vereines*, Vienna, Austria.
(54) *Den Tekniske Forenings Tidsskrift*, Copenhagen, Denmark.
(55) *Ingeniören*, Copenhagen, Denmark.
(56) *Teknisk Tidskrift*. Stockholm, Sweden.
(57) *Teknisk Ugeblad*, Christiania, Norway.
(58) *Proceedings*, Eng. Soc. W. Pa. 410 Penn Ave., Pittsburg, Pa. 50c.
(59) *Transactions*, Mining Institute of Scotland, London and Newcastle-upon-Tyne.
(61) *Proceedings*, Western Railway Club. 225 Dearborn St., Chicago, Ill., 25c.
(62) *American Manufacturer and Iron World*, 59 Ninth St., Pittsburg, Pa.
(63) *Minutes of Proceedings*, Inst. C. E London, England.

LIST OF ARTICLES.

Bridge.

Reactions in Swing-Bridge Trusses. Willis Whited. (58) February.
Arched Bridges over the Rhine.* (11) Serial beginning Feb. 9, ending June 8.
Special Bridge and Viaduct Construction in Western Pennsylvania.* (14) Serial beginning April 28, ending June 2.
Viaduct Approaches for the New East River Bridge at New York City.* (13) May 10.
The Towers and Approaches of the New East River Bridge.* (46) May 12.
Eight-Track Rolling-Lift Drawbridge over the Chicago Drainage Canal.* (13) May 24.
Bridge Deflections under High Speed.* Malverd A. Howe. (15) May 25.
The Scherzer Type of Bascule Drawbridge.* (12) June 1.
Bridge Inspection on the Erie Railroad. (14) June 2.
A Rolling-Lift Bridge at Cleveland.* (40) June 8.
Working Swing Bridges by Electricity.* (12) June 8.
The Bellefield Stone Arch Bridge, Pittsburg.* (14) June 9.
The Duluth and Superior Bridge.* (14) June 23.
The Exhibit of Typical American Bridges at the Paris Exposition.* Geo. L. Fowler. (13) July 5.
The Chicago Type of Bascule Bridge.* (14) July 21.
The Failure and Repair of the Piers of the Aqueduct Bridge, Washington, D. C.* L. R. Grabill. (13) July 26.
Repairing a Bridge Pier by means of an Annular Pneumatic Caisson.* Edward M. St. John. (13) August 2.
Nouveau Type de Pont Suspendu Rigide. (33) May 5.
Pont de l'Oued Endja (Algérie).* (33) June 16.

Electrical.

The Polyphase Distributing System of the Metropolitan Street Railway Company of New York City.* J. E. Woodbridge. (27) Serial beginning March 31, ending June 9.
A New Transmission Dynamometer.* W. Elwell Goldsborough. (42) April.
Wave Transmission over Non-Uniform Cables and Long Distance Air-Lines. M. I. Pupin. (42) April.
The Electrical Equipment of Ships of War.* (26) Serial beginning April 6, ending May 4.
A Practical Transmitter Using the Sine Wave for Cable Telegraphy; and Measurements with Alternating Currents upon an Atlantic Cable.* Albert C. Crehore and George O. Squier. (42) May.
Willesden Electric Supply Works.* (12) May 4.
On Distant Electric Power Transmission. Prof. George Forbes. (26) Serial beginning May 11, ending May 25.
The Properties of Carbon in Electrical Work. Elihu Thomson. (27) Serial beginning May 12, ending May 26.
Coventry Corporation Electricity Works.* (26) May 18.
Electrical Winding and Haulage Machinery.* W. Müller. (22) Serial beginning May 18, ending June 8.
The Central-Station Situation in the City of Chicago.* (27) May 19.
Running Collieries Entirely by Electricity from One Center. Sydney F. Walker. (22) May 25.
Electromagnetic Mechanism, with Special Reference to Telegraphic Work. R. A. Fessenden. (3) Serial beginning June, ending August.
Electric Motor Carriages.* (26) June 1.
The Cost of Electric Power Production. Philip Dawson. (11) Serial beginning June 1, ending June 29.
Report of the National Electric Light Association Committee upon the Photometric Value of Arc Lamps.* (27) June 2.
The Power-Generating Plant at the Paris Exposition.* (19) June 16.
The Electrical Plant at the Parkgate Steelworks.* (22) June 22.
Mutual Inductance of Three-Phase Circuits.* Aug. J. Bowie, Jr. (27) June 23.
The Electric Automobile. A. L. Riker. (19) June 23.
The United Electric Light and Power Company of New York City.* (27) June 23.
Electrical Measurements of Work or Energy. G. L. Addenbrooke. (9) July.
Copper Saving in the Joint Transmission of Direct and Alternating Currents. Frederick Bedell. (26) July 6.
Electrically-Driven Printers' Machinery.* (12) July 13.
Electric Automobiles at the Paris Exposition.* (27) July 14.
Electrolysis of Underground Metal Structures.* Dabney H. Maury. (13) July 19.
The Incandescent Lamp. Ed. C. De Segundo. (26) Serial beginning July 20, ending July 27.
Electric Driving. H. A. Mavor. (47) July 21.
Cost and Limitation of Electric Vehicle Traction. Alton D. Adams. (46) July 28.
The Design of Tractive Electromagnets.* W. Elwell Goldsborough. (27) July 28.
Alternating Current Generators. H. G. Heist (24) July 30.
Electric Power in the Parkgate Steelworks, England.* (27) August 4.
Electrolysis in Providence, R. I.* (14) August 4.
Télégraphie Multiple Réversible ou Multiplex: Système E. Mercadia.* G. Briand. (33) June 16.

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* Illustrated.

Marine.

Notable Incidents in Early Ocean Steam Navigation. (12) Serial beginning March 16, ending June 1.
Admiralty Engineering. (12) Serial beginning March 30, ending May 18.
The New Telegraph Steamer *Von Podbielski*.* Prof. Jamieson. (26) Serial beginning May 4, ending May 25.
The Japanese Battleship *Asahi*.* (11) Serial beginning May 25, ending June 29.
The Demonstrated Success of the Submarine Boat.* Rear Admiral Philip Hichborn. (9) June.
The Action of Bilge Keels. G. H. Bryan. (11) June 1.
Dry Dock with Steel Caisson Foundations at the Port of Toulon, France.* (13) June 7.
Corrosion and Failure of Propeller Shafts.* A. Scott Younger. (11) June 15.
Naval Docks of the United States.* Waldon Fawcett. (62) June 28.
The Ship-Building Yards of the United States.* Waldon Fawcett. (9) Serial beginning July, ending August.
The Distribution of Pressure due to Flow round Submerged Surfaces, with Special Reference to Balanced Rudders.* Professor H. S. Hele-Shaw. (11) Serial beginning July 13, ending July 20.
Partial Failure of Coffer Dam, New Dry Dock, Boston Navy Yard.* Frank O. Maxson. (14) August 4.
Classification et Utilisation Militaire des Sous-Marins. H. Noalhat. (36) June 25.

Mechanical.

Engine Tests. George H. Barrus. (14) Serial beginning Feb. 17, ending April 14.
The Gas Engine in Practical Use.* J. D. Lyon. (58) April.
Recent Developments in Hydraulic Lifts. (47) Serial beginning April 28, ending May 5.
An Inertia Valve Percussive Tool.* Chester B. Albree. (58) May.
Fly-Wheel Accidents.* (22) May 4.
Road Locomotion.* Professor H. S. Hele-Shaw. (12) Serial beginning May 4, ending June 8.
On the Manufacture and Application of Water-Gas.* Carl Dellwik. (22) May 11.
The Modern Gas Engine.* James Dunlop. (47) Serial beginning May 12, ending May 26.
Inclined Retorts at the Bankside Works of the South Metropolitan Gas Company, London, England.* C. C. Carpenter. (24) May 21.
The Automobile Wagon for Heavy Duty.* Arthur Herschmann. (47) Serial beginning May 26, ending June 2.
Some Points on Slow-Speed Engine Design.* A. Marshall Downie. (47) Serial beginning May 26, ending June 9.
Experiments on Using Gasoline Gas for Boiler Heating. Herman Poole. (47) June 2.
Stationary Shop Boilers. F. W. Dean. (15) June 15.
Boiler Testing. (47) Serial beginning June 16, ending June 30.
Open-Hearth Steel Boiler Plates.* T. L. Condron. (15) June 22.
The Design of Steam Power Plants. Henry C. Meyer, Jr. (14) Serial beginning June 23, ending July 14th.
Electrically-Driven Air Compressor.* (12) June 29.
Experiments with a Boiler Arranged to Serve as a Calorimeter for Determining the Heating Value of Coal. Charles J. Slipper, E. Mortimer Harrison and Edward C. Schmidt. (8) July.
Foundry Cranes.* Joseph Horner. (10) July.
Modern Methods of Manufacturing Gas; with a description of Its Distribution under High Pressure. (2) July.
The Development of Fly-Wheels.* Charles H. Benjamin. (10) July.
Utilizing the Waste Heat from the Gas Engine. Alton D. Adams. (9) July.
Gas Engine Experiments.* Prof. W. W. F. Pullen. (47) July 7.
Power Transmission by Shafting *vs.* Electricity. (18) July 7.
The New Air Ship of M. De Santos Dumont.* (46) July 7.
"The New Gas." W. H. Y. Weber. (24) July 9.
Some Notes On the Application of Motors in an Iron and Steel Plant.* (27) July 14.
Naphthaline from Retort to Point of Deposition. William Young. (24) July 16.
The Valves of Internal Combustion Engines.* James D. Roots. (12) July 20.
Cylinder Proportions for Compound and Triple-Expansion Engines.* B. C. Ball. (47) July 21.
Testing a Blast Furnace Gas Engine. (62) July 26.
Blast Furnace Gas Engine.* (41) August.
Electric Cranes in German Harbors.* Louis J. Magee. (10) August.
Starters for Gas Engines.* (41) August.
The Fellows Machine and Cutter for Generating Gear-Teeth.* (3) August.
The Future of Power Development: The Outlook for the Steam Engine and other Forms of Prime Mover. William D. Ennis. (9) August.
Speed Variations Occurring during the Cycles of the Otto Gas Engine and the Diesel Heat Motor.* (13) August 2.
Some Notes on Larger Types of Gas Engines. J. B. Crockett. (24) August 6.
Hauling and Pumping Underground by an Oil-Engine. William Smith. (59) vol. xxi, pt. 3.
Calorimètrie Graphique de la Machine à Vapeur. Fritz Krauss. (37) May.

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Mechanical—(Continued).

La Théorie de la Machine à Vapeur. Anspach. (37) June.
Les Gazogènes Riché.* P. Corbier. (33) June 30.
Chaudière Multitubulaire. Système Delpeutte.* Pierre Guedon. (34) July.
Essai d'une Machine Soufflante à Gaz de Haut Fourneau.* (36) July 10.

Military.

Modern Field Artillery.* (11) Serial beginning March 2, ending May 25.
Disappearing Gun Carriages in the United States.* G. H. Powell. (9) June.
New Ferracute Presses for Cartridge Works.* (20) May 24.
Notes on the Construction of "Long Cecil," a 4.1-in. Rifled Breechloading Gun, in Kimberly during the Siege, 1899-1900.* Edward Goffe. (11) June 29.
Building Big Guns. James Eastus Price. (41) August.

Mining.

Losses in the Determination of Gold and Silver in Copper Bullion: Their Causes, and a Method for Overcoming Them. W. Randolph Van Liew. (16) Serial beginning April 21, ending April 28.
Electricity in Mining: Principles Governing the Calculation, Construction, and Operation of Electrical Installations. R. B. Williamson. (45) Serial beginning May, ending August.
Notes on the Working of Coal Mines under Sea. Thomas Bell. (22) Serial beginning May 4, ending May 18.
Working Twin Seams of Coal.* W. S. Gresley. (16) Serial beginning May 12, ending May 26.
The Ray Copper Mines, Arizona.* Alexander Hill. (16) May 19.
Draining Gas from Gob Workings. Chas. Connor. (45) June.
Gold Placers in Glaciated Regions.* Prof. George H. Stone. (45) June.
On the Theory of Timbering: The Need of Data at Present Unknown, Which can only be Derived from Experiment.* Henry Louis. (45) June.
Precipitation of Gold from Cyanide Solutions. H. Watson. (41) June.
Pike's Peak Company's Power Plant.* (41) June.
Sinking Parker Shaft at Zinc Mines, Franklin Furnace, New Jersey.* J. A. Van Mater. (45) June.
Mining Accidents and Their Prevention. George Farmer. (22) June 1.
Electrical Coal-Mining Machines. (46) June 23.
Coal Mining at the Paris Exhibition of 1900.* (22) June 29.
Safety Lamps—Past and Present.* (22) Serial beginning June 29, ending July 6.
Notes on Lead Smelting and Gold and Silver Refining: The Fallis Manometer.* Malvern W. Iles. (16) June 30.
Peculiarities of Mine Mechanics.* J. C. Taylor. (41) July.
The Red Ash Mine Disaster: A Description of the Mine and the Conditions Existing before the Accident—Suggested Changes in Mine Law. James W. Paul. (45) July.
Gold Mining in Georgia.* (46) July 7.
Dangerous Outcrops under Quicksand Deposits.* (22) July 13.
Roads for Mining Purposes. Captain C. C. Longridge. (11) July 13.
Placer-Mining in the Southern Ourals. Charles Tappan. (16) Serial beginning July 14, ending July 21.
The Nature and Yield of Metalliferous Deposits.* Bennett H. Brough. (29) July 20.
Prospecting in the Philippines. G. D. Rice. (62) July 26.
Argo, or Newhouse Tunnel; the Purposes for which it is being Driven and the Method of Driving.* Prof. Arthur Lakes. (45) August.
Coal Mines of Pictou: A Description of the Mines of the Colorado Fuel & Iron Co., the Methods of Operation and the Geological Formation.* Frank Meade. (45) August.
Electric Mining Machinery in the British Collieries.* Sydney F. Walker. (9) August.
Mine Timbering: Various Methods of Cutting and Placing Timbers to Secure the Best Results.* David J. Evans. (45) August.
Some Problems in Deep Coal Mining. H. M. Chance. (3) August.
Iron Lining for Colliery Shafts.* M. E. Cleve. (16) August 4.
Mines de Lignite de Gardanne (Bouches-du-Rhône): Construction d'une Galerie Souterraine Destinée à Relier la Concession à la Mer.* H. Schmerber. (33) Serial beginning May 26, ending June 9.

Municipal.

The Improvement of Our Roads. A. Moresby White. (29) May 11.
Parks and Boulevards. A. C. Schrader. (4) June.
Progress toward Uniform Municipal Statistics in the United States. (13) July 5.

Railroad.

English and American Railways. (12) Serial beginning Dec. 1, 1899, ending March 30, 1900.
Dublin Electric Tramways.* (26) Serial beginning April 20, ending May 4.
Locomotive Road Tests: How should they be made? L. P. Breckenridge. (61) May.
On the Economical Size of Goods Trucks. Charles Oliver. (21) May.
Some Points about Steel Forgings for Locomotives. H. F. J. Porter. (39) May.
Railway Car Wheels.* (22) May 4.

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Railroad—(Continued).

Manual Controlled and Automatic Signals. Alexander Holley Rudd. (13) May 10.
The Jungfrau Three-Phase Electric Railway.* W. H. Molesworth. (27) May 12.
Low-Pressure Pneumatic Interlocking at Jersey City.* (15) May 25.
The Controlled Manual and Automatic Block Signaling Systems. C. C. Anthony. (15) Serial beginning May 25, ending June 1.
Consideration of Weight of Parts in Locomotive Design. W. H. Marshall. (25) June.
Locomotive Design.* F. J. Cole. (25) June.
Railway Bearings: An Investigation of Causes of Hot Boxes in Railway Service, and Methods for Their Prevention.* Robert Job. (3) June.
The Ventilation of Passenger Cars. C. B. Dudley and F. N. Pease. (25) June.
Locomotive Tenders: Several Examples of Improved Practice.* William Forsyth. (25) Serial beginning June, ending July.
Central London Railway.* (26) Serial beginning June 1, ending June 29.
The Lexington & Boston Electric Railway.* (17) June 2.
Heavy Track Construction in New Orleans.* (17) June 2.
Engineering Records in the Railroad Operating Department. C. E. Cartwright. (15) June 8.
Locomotive Engines at the Paris Exhibition.* (12) June 8.
The Lyman Pneumatic Crossing Signal.* (15) June 8.
Rails and Rail Joints.* (19) June 9.
A System of Signaling for Railways.* W. S. Boult. (13) June 14.
Lubrication and Hot-Boxes. H. B. Hodges. (15) June 15.
Tests of Westinghouse and New York Triple Valves.* (15) June 15.
Railroad Concrete Masonry. W. A. Rogers. (15) Serial beginning June 15, ending July 27.
Renewing Ballast on the Michigan Central Ry.* (18) June 16.
Types of American Narrow Gauge Locomotives.* (47) Serial beginning June 16, ending June 23.
Center Plates and Side Bearings for Freight Cars.* (13) June 21.
Coke for Locomotive Fuel.* George L. Fowler. (15) June 22.
Development of the Structural Steel Hopper Car.* George I. King. (40) June 22.
What is the Ideal Fast Passenger Engine?* S. M. Prince, Jr. (15) June 22.
Exhaust and Draft in Locomotives.* (15) June 29.
Recent Locomotive Practice in France.* Edouard Sauvage. (12) Serial beginning June 29, ending July 6.
The Most Economical Size of Freight Cars. L. F. Loree. (15) July 6.
The State Railways of France at the Paris Exhibition.* (11) Serial beginning July 6, ending July 20.
Electric Lighting of Railway Trains.* Geo. D. Shepardson. (27) July 7.
Some Notes on the Operation of the Power Plant of the Chicago & Milwaukee Electric Railway Company.* (17) July 7.
The Largest Electric Railway Company in Germany.* (17) July 7.
The Paris Exposition Third-Rail Road.* (27) July 7.
New Passenger Station at Richmond.* (15) July 13.
The Railways of China.* (22) July 13.
Transportation of Freight. Russell Harding. (18) July 14.
Wooden Box Cars and Coal Cars of 100 000 lbs. Capacity; Southern Pacific Ry.* (13) July 19.
Highway Crossing Alarms. J. S. Evans. (15) July 20.
A New Compound Locomotive.* John Riekie. (12) July 20.
Renewing Steel Rails.* (22) July 20.
Southampton Corporation Electric Tramways.* (26) July 20.
The Work of the Light Railway Commission. R. H. Scotter. (26) July 20.
The Central London Underground Railway.* (27) July 21.
Car Lighting with Acetylene.* J. M. Morehead. (40) July 27.
Acetylene in Station and Train Lighting. A. Lipschutz. (18) July 28.
Railroad Dynamometer and Test Car, Illinois Central R. R.* (13) August 2.
Compressed Air Cars in New York.* (17) August 4.
Construction Work on the Tennessee Central Ry.* (18) August 4.
Testing and Repairing Methods of the North Jersey Street Railway Company.* (17) August 4.
Recent Improvements in the Southwest Missouri Electric Railway System.* (17) August 4.
The Neal-Jupiter Brake.* (17) August 4.
Locomotive Compound Articulée: Système Mallet. A. Mallet. (38) May.
Note sur le Graissage des Locomotives Américaines.* Oudet. (38) June.
Les Signaux en Usage sur les Lignes de l'État Belge. C. Rollin. (38) June.
Rapports au Comité de l'Exploitation Technique des Chemins de Fer sur le Frein à Air Comprimé: Système Lipkowski. (43) First trimestre, 1900.

Sanitary.

Difficulties Encountered in Building the Storage Well for the Sewerage System of Concord, Massachusetts.* Leonard Metcalf. (1) May.
The Thackeray Garbage Furnaces at San Francisco, Cal.* F. J. Mills. (13) May 17.
Sewer Maintenance. W. C. Parmley. (1) June.

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Sanitary—(Continued).

The Towns' Refuse Problem. (26) Serial beginning June 1, ending June 8.
Sewage Disposal at Sheffield, England. (14) June 9.
Cleaning Catch-Basins and Sewers. A. Prescott Folwell. (14) June 16.
The Bacterial Treatment of Sewage in England.* Wm. Easby, Jr. (2) July.
Garbage Reduction at Columbus, Ohio. (13) July 19.
The Management of Sewage Farms. (14) August 4.
Les Grands Collecteurs de la Ville de Dijon. Charles Mocquery. (43) First trimestre, 1900.

Structural.

Nickel Steel: A Synopsis of Experiment and Opinion. David H. Browne. (47) Serial beginning Jan. 27, ending May 5.
Architectural Acoustics. Prof. Wallace C. Sabine. (14) Serial beginning April 14, ending May 26.
The Theory and Practice of Protective Coatings for Structural Metal. A. H. Sabin. (2) May.
The Use of Fluid Metal In the Open-Hearth Furnace. James Riley. (11) May 11.
Concrete Arches.* Daniel B. Luten. (15) Serial beginning May 11, ending May 18.
Foundations for High Buildings in the City of Mexico. (18) May 12.
Ventilation and Heating, Appellate Court House, New York.* (14) May 12.
Hot Water Heating from a Central Station.* H. T. Yaryan. (20) May 17.
The Proposed American Standard Specifications for Steel. (20) Serial beginning May 17, ending May 24.
Some Notes on Pipe Founding.* E. Kebler. (22) May 25.
Equalisation of the Varying Temperatures of Hot Blast.* Lawrence F. Gjers and Joseph H. Harrison. (47) May 26.
The Newark Armory Drill Hall.* (14) May 26.
Monier Constructions.* E. Lee Heidenreich. (4) June.
The New Engineering Building of the University of Wisconsin.* J. B. Johnson. (4) June.
Tests of Fire Retardent Materials. Charles L. Norton. (7) June.
Manufacture of Slag Cement. *Ritter* Cecil von Schwarz. (14) June 2.
The Michigan Alkali Co.'s Plant for Manufacturing Portland Cement from Caustic Soda Waste.* B. B. Lathbury. (13) June 7.
The Chimney of the Metropolitan Street Railway Company's Power House, New York.* William Wallace Christie. (15) June 8.
The Seventy-Fourth Regiment Armory, Buffalo.* (14) June 9.
Crystallization of Metals.* Edward B. Gilmour. (20) June 14.
The Manufacture of Cold-Drawn Steel Tubes.* (40) June 15.
The Preservative Treatment of Timber.* (22) June 15.
The Pyritic Smelting of Copper Ores. Captain C. C. Longridge. (11) June 15.
Ventilation and Heating of the Law School Building, University of Pennsylvania.* (14) June 16.
Cupola Practice in Bessemer Steel Works.* S. M. Rodgers. (20) June 21.
The Open-Hearth Continuous Steel Process. Benjamin Talbot. (11) June 22.
The Use of Oil in Metallurgical Furnaces in Russia.* (16) June 23.
Making "Best Yorkshire" Iron.* Ewing Matheson. (10) July.
The Hamilton Steel & Iron Company's New Steel Plant.* (20) July 5.
A Modern English Blast Furnace: The Millom & Askam Hematite Iron Company, Limited.* Axel Sahlin. (20) July 12.
The Working of Bessemer Converters. (22) July 20.
The Lukens Iron and Steel Company's New Plant.* (20) July 26.
A New Method of Constructing Blast Furnaces.* (22) July 27.
The Virginia Portland Cement Company's Works.* Watson Vredenburgh, Jr. (14) July 28.
Relations between Physical and Chemical Tests of Cement. Otto H. Klein and S. F. Peckham. (14) August 4.
Le Nouvel Hippodrome.* (36) April 25.
Murs de Soutènement et Passereile du Quai Debilly, à Paris, en Bêton de Ciment Armé, Système Hennebique.* Paul Sarrey. (35) May.
Note sur l'Emploi d'Injections de Ciment à l'Air Comprimé dans les Maçonneries, Terrains de fondations, etc.* Caméré. (43) First trimestre, 1900.

Topographical.

The Survey of the Mouths of the Yukon River, Alaska.* G. R. Putnam and R. L. Faris. (13) June 7.

Water Supply.

The Reconstruction of the Big Hole Dam. Jos. H. Harper. (1) April.
Mr. Freeman's Report on the New York Water Supply.* (14) Serial beginning April 14, ending April 21.
The Water Supply of New Orleans. Prof. John M. Ordway. (1) May.
Irrigation Works on the Nile.* (12) May 11.
Report on Water Purification Experiments at Washington, D. C. (13) May 17.
The Sault Power Canal.* Waldon Fawcett. (46) May 26.

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Water Supply—(Continued).

Outline of the Geology of Long Island in its Relations to the Public Water Supplies. W. O. Crosby. (7) June.
The Mt. Prospect Laboratory of the Brooklyn Water-Works, Greater New York.* George C. Whipple. (13) June 7.
Water Softening Plant at the Lorain Steel Company's Blast Furnaces.* N. O. Goldsmith. (20) June 14.
Examination of the Drinking Water of Brooklyn, N. Y.* (46) June 30.
The Relationship between the Cost of Water Wasted and the Cost of Detection and Prevention of Waste. A. J. Jenkins. (12) Serial beginning July 6, ending July 13.
The Jersey City Water-Works.* (14) July 21.
Filtres Dégrossisseurs pour Grandes Masses d'Eau.* A. Puech. (32) May.
La Stérilisation des Eaux Alimentaires.* Albert Bergé. (32) June.
Les Eaux Souterraines et Leur Captation au Moyen de Puits.* L. Brouhon. (30) June.
Note sur les Dimensions à Donner aux Réservoirs des Distributions d'Eau. Ch. Vigreux. (33) July 21.

Waterways.

Sea Level Canal Across the Isthmus of San Blas. W. W. Redfield. (1) May.
The Hotopp Syphon Locks on the Elbe-Trave Canal.* (11) May 4.
Deep Sea Dredges and Dredging.* Waldon Fawcett. (62) May 24.
Self-Propelling Hydraulic Dredge for the Mississippi River.* (13) May 31.
The East Minnesota Ore Dock.* Dwight E. Woodbridge. (20) June 21.
Methods and Results of Surveys and Borings for Oswego-Mohawk Ship Canal Route. D. J. Howell. (13) Serial beginning June 21, ending June 28.
Hydraulic Pile-Screwing.* C. W. Anderson. (24) June 25.
The Reaction Breakwater as Proposed for the Opening of the Southwest Pass of the Mississippi River.* Lewis M. Haupt. (3) July.
The Topography of the Nicaragua Canal Route and the Plans and Estimated Cost of Constructing the Canal.* E. S. Wheeler. (13) July 12.
A Large Steel Pier Shed.* (14) July 28.
Le Canal de Panama Historique: Étude et Discussion du Projet de la Nouvelle Compagnie.* A. Dumas. (33) Serial beginning April 7, ending April 28.
L'Exploitation des Voies Navigables de la Belgique. A. Debeil. (30) June.
Mémoire sur un Canal de Navigation Latéral au Rhône. (35) Serial beginning June, ending July.
Les Ports Tunisiens.* G. Leugny. (36) July 25.

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* Illustrated.

NEW BOOKS OF THE MONTH.

Unless otherwise specified, books in this list have been donated to the Library by the Publisher.

TOPOGRAPHIC SURVEYING.

Including Geographic, Exploratory, and Military Mapping, with Hints on Camping, Emergency Surgery and Photography. By Herbert M. Wilson, M. Am. Soc. C. E. Cloth, 9 x 6 ins., 30 + 910 pp., illus. New York, John Wiley & Sons, 1900. $3.50.

The author has aimed to bring together in one volume the data essential to a comprehensive knowledge of topographic surveying and to cover the varied phases of all classes of surveys which are made with a view to representing on maps information relative to the features of the earth's surface. The methods elaborated are chiefly those which have been developed in recent years by the great government surveying organizations and by such few private corporations as have kept in touch with the most modern practice. The book is devoted practically to higher surveying and presupposes a knowledge of all the more elementary branches.

A HUNDRED YEARS OF GERMAN BRIDGE BUILDING.

By Georg C. Mehrtens. Published for the Paris Universal Exhibition, 1900; tr. fr. the German by Ludwig Mertens. ¾ cloth, 15 x 11 ins., 135 pp.; illus. Berlin, Julius Springer, 1900.

This work treats of the development of German bridge construction with regard to theory, design and erection, supplemented by a description of the paintings, models, etc., exhibited by German bridge-building firms at the Paris Exposition. The contents are:

Introduction; The History of Girder Systems and of the Theory of Bridges; Improvements in the Construction of Iron Bridges; Bridge-Building Companies and Their Work; Appendix.

MEMBERSHIP.

ADDITIONS.

MEMBERS.

		Date of Membership.
Adam, Robert, Chf. Eng., Vera Cruz Harbor Work, 58 Apartado de Correo, Vera Cruz, Mexico		May 2, 1900
Atwood, John Abiel, Chf. Eng., Pittsburg and Lake Erie R. R., Beaver, Pa.		Jan. 3, 1900
Bardol, Frank Valentine Erhard, Chf. Eng., Bureau of Engineering, 437 East Utica St., Buffalo, N. Y.		May 2, 1900
Body, John Benjamin, Gen. Man., Tehuantepec National Ry., Coatzacoalcos, Mexico	Assoc. M. M.	Oct. 2, 1895 May 2, 1900
Farley, Godfrey Pearson, Gen. Man. and Chf. Eng., Wiscasset and Quebec R. R., Chf. Eng., Maine Water & Electric Power Co., Wiscasset, Me		June 6, 1900
Hayes, Stanley Wolcott, Div. Eng., Western Div., N. Y. C. & H. R. R. R., Buffalo, N. Y.		June 6, 1900
Irwin, James Clark, Div. Eng., Middle Div., N. Y. C. & H. R. R. R.; Res. 162 Chestnut St., Albany, N. Y.	Jun. Assoc. M. M.	Apr. 4, 1893 Dec. 7, 1898 June 6, 1900
Kennedy, James Henry, St. Thomas, Ontario, Canada		May 2, 1900
Langton, John, 72 Trinity Place, New York City		May 2, 1900
Lee, Edward Hervey, Eng. and Gen. Roadmaster, C. & W. I. R. R. Co. and The Belt Ry. Co. of Chicago, Chicago, Ill		June 6, 1900
Moncure, William, Supt., 2d Div., Seaboard Air Line, Raleigh, N. C		May 2, 1900
Morse, Edwin Kirtland, 1206 Carnegie Bldg., Pittsburg, Pa		June 6, 1900
Oakley, Frank Thompson, 1033 The Spitzer, Toledo, Ohio	Assoc. M. M.	Feb. 6, 1895 June 6, 1900
Patterson, John Austin, 420 Walnut St., Philadelphia, Pa		May 2, 1900
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Correa, Edward Arnold.........Elected Member March 7th, 1900; died June 24th, 1900.

Curtis, William Giddings........Elected Member May 3d, 1882; died June 15th, 1900.

Eayrs, Norman Wilder..........Elected Member June 3d, 1885; died May 13th, 1900.

Hasell, Bentley Douglas.......Elected Member July 3d, 1878; died May 29th, 1900.

Huntington, Collis P...........Elected Fellow March 10th, 1877; died Aug. 13th, 1900.

Lindenthal, Dominik............Elected Assoc. M. March 4th, 1896; died June 8th, 1900.

Reiseger, Marc John............Elected Member Dec. 7th, 1898; died May 26th, 1900.

Smith, Hamilton................Elected Member Feb. 5th, 1879; died July 4th, 1900.

Vol. XXVI. AUGUST, 1900. No. 6.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS AND DISCUSSIONS.

Note.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

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THE NINETY-SIXTH STREET POWER STATION OF THE METROPOLITAN STREET RAILWAY COMPANY, OF NEW YORK CITY.

By L. G. Montony, Assoc. M. Am. Soc. C. E.

To be Presented September 19th, 1900.

The events which led up to the building of the new power station of the Metropolitan Street Railway Company were brought about largely by the steady growth of the company.

In 1891 it was decided to adopt mechanical traction for Broadway, and the cable was selected as offering the best tractive power for heavy loads. As the company increased in size, cable extensions were built on Lexington and Columbus Avenues. Having built these, and having laid out other proposed roads, it was seen that the cable, by its multiplicity of sheave pits, curve pits and power houses, was too expensive and cumbersome to be adopted for a large system; and, as the overhead trolley, which had proven so satisfactory in other cities, was prohibited on Manhattan Island, the company began a search for some other system which would prove satisfactory in operation and which would also overcome the objectionable features of both the foregoing systems.

Note.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers with discussion in full will be published in *Transactions*.

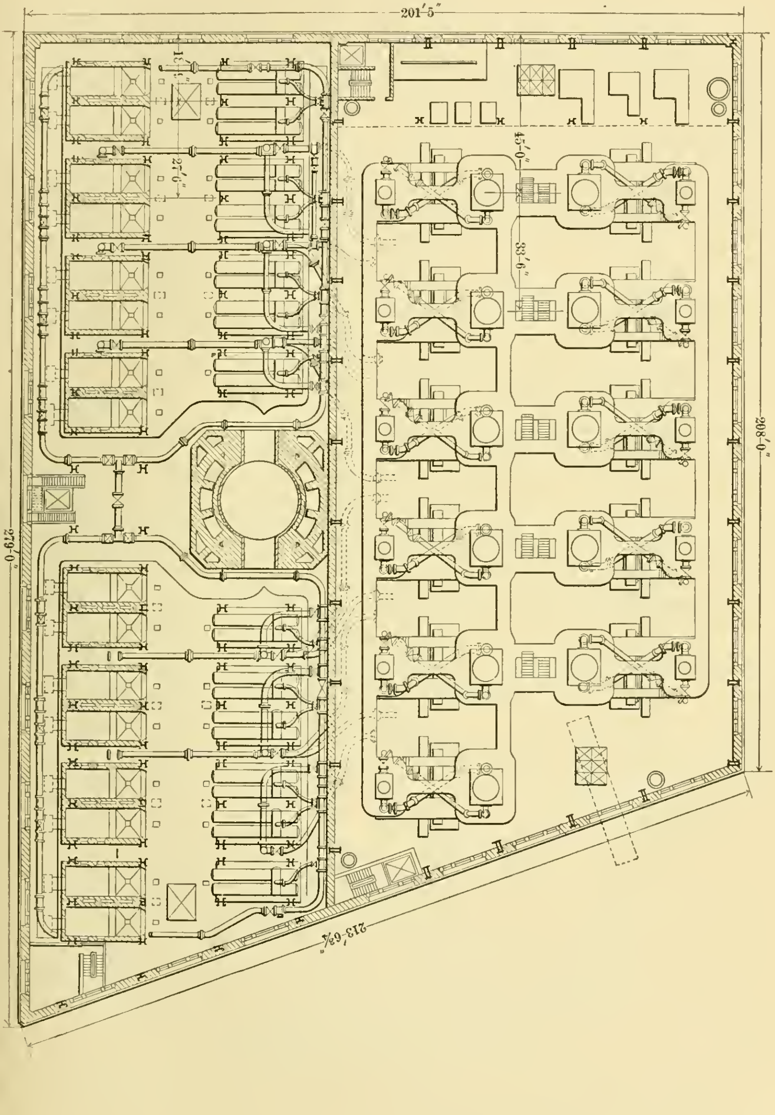


Fig 1

After a careful study of all the underground conduit roads in existence at that time it was decided to build and equip several miles of conduit electric road, experimentally; making the road-bed so that it could be easily changed to a cable road if the experiment failed. This experimental line was built in 1895, and proved so satisfactory that it was decided to adopt the conduit electric trolley as a standard for all main lines. The company now operates all the lines in the Boroughs of Manhattan and The Bronx. Each year, since 1897, it has converted several roads into the conduit electric construction, and when the conversion of the present cable roads is completed, nearly all the main lines will be of this type. All the street railroads in The Bronx are of the overhead-trolley type. The cross-town lines down town are as yet unequipped, because the underground trolley does not seem to be suitable, and the company is still conducting experiments with a view to securing a motive power for them.

Location.—The station is located on First Avenue between Ninety-fifth and Ninety-sixth Streets, and the property extends to the East River. The dimensions of the building are shown on the plan, Fig. 1. Provision has been made for a marginal street along the river front, by leaving a space about 75 ft. wide between the building and the river, in case the Dock Department should ever conclude to condemn and purchase that strip.

The engine house is on the north and the boiler house on the south side of the building. The width of the former is about 112 ft., and of the latter about 88 ft. The chimney is near the center of the boiler room. Fig. 2 is a longitudinal section of the boiler house, Fig. 3 a longitudinal section of the engine room, and Fig. 4 a cross-section through the building.

The space opposite the chimney, in the center of the boiler house, is utilized as follows: In the basement this space contains the water supply piping; on the first floor it contains the feed pumps; the second and third floors are left for secondary heaters; the fourth is for an oil room, and the fifth is used as a machine shop for light repairs. An elevator and a stairway provide access to each floor.

On each of the first, second and third floors space is provided for two large blowers to be used for forced draft if it be found advisable or necessary to force the boilers.

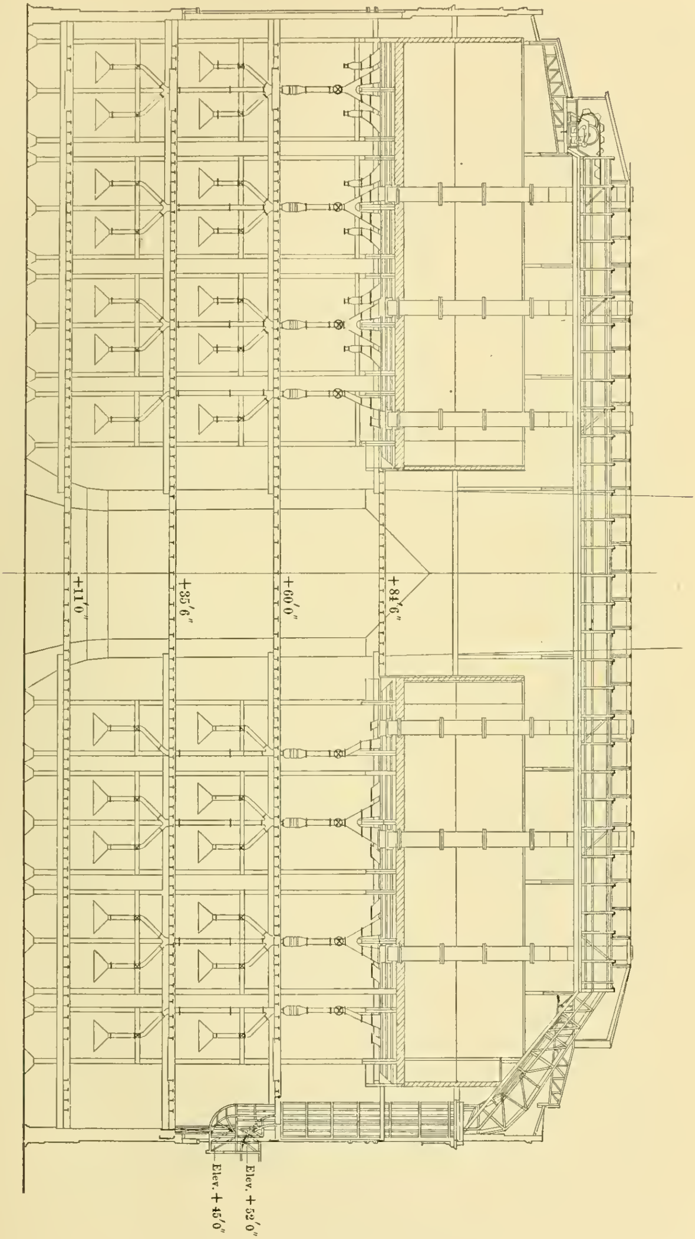


FIG. 2.

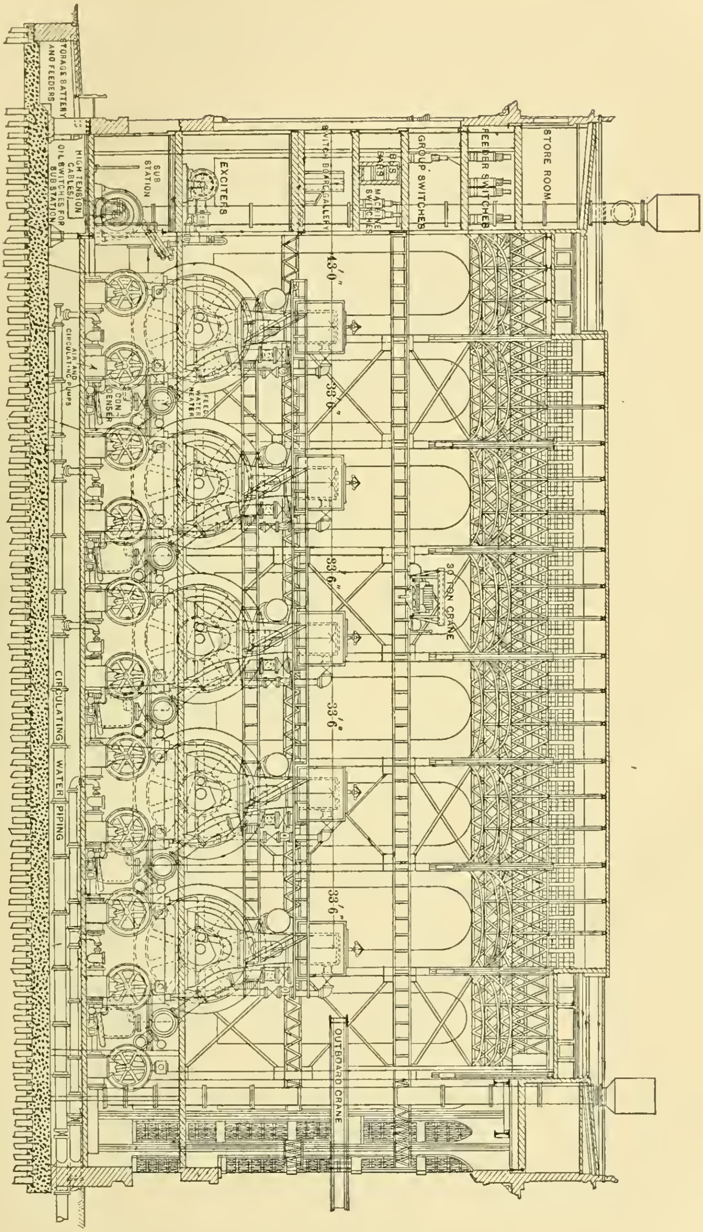
At the southeast corner there is a space divided up into a stairway well and a wash room on each boiler house floor for the men. Over each wash room there is a mezzanine floor for lockers, etc.

The Foundations.—Piles were driven over the whole site and then a thick bed of concrete was put in. The thickness of the concrete under the chimney is 20 ft.; under the center of the boiler house it is 7 ft., and under the remainder of the building 5 ft. The piles are from 35 to 40 ft. long, and extend up into the concrete 1 ft. Those under the chimney are 45 ft. long. The piles were not driven entirely to refusal, yet they are firmly embedded in the coarse sand or gravel, and, according to the *Engineering News* formula, they have a sufficient bearing power.

Near the present westerly property line of the site there was an old bulkhead crib, and old cribs extended out along Ninety-fifth and Ninety-sixth Streets, formerly making piers near these streets. The site of the building was formerly the water slip, and therefore the upper part of the excavation was mostly filled material of comparatively recent date.

The cribs extend down near each street line, and are part way under the building. It was found that, by removing the tops of these cribs, when the excavation was being made, it was possible to drive piles somewhat regularly and sufficiently well through the bottom part. Some of the piles were shod. The cribs did not extend under the area occupied by the chimney. The preliminary borings indicated that the space between the cribs was filled with heterogenous matter down to about Elevation — 15. Under this, and down to about Elevation —75, there were beds of sand, each about 10 ft. in thickness, and growing coarser and more like hardpan as the depth increased. The strata below the cribs seem to be almost level over the whole site. Below Elevation —75 stiff blue clay extends down indefinitely as far as known. The piles were driven on nearly 3-ft. centers under the walls, and on 30-in. centers under the center of the building. Under the chimney they were driven a little closer, being placed so that the triangle formed by each three adjacent piles has 30 ins. on a side. The elevation of the former surface of the ground was from + 6 to + 7 ft. The elevation of the basement is zero.

A vault has been built under the sidewalk on Ninety-fifth Street and on First Avenue, with the floor at Elevation — 2. This will be used for



LONGITUDINAL SECTION THROUGH ENGINE ROOM.

LOOKING NORTH

Fig. 3.

the distribution of feeder wires and probably for a small storage battery. There is piling under the wall, and a thick bed of concrete for the floor, which is not piled.

The engine foundations are shown in Fig. 2, Plate XXVII. They are mostly of brick, but the lower part, below the holding-down bolts, consists of a shell of brick filled in with concrete. Each of the large foundations would contain about 500 000 brick if entirely built of them.

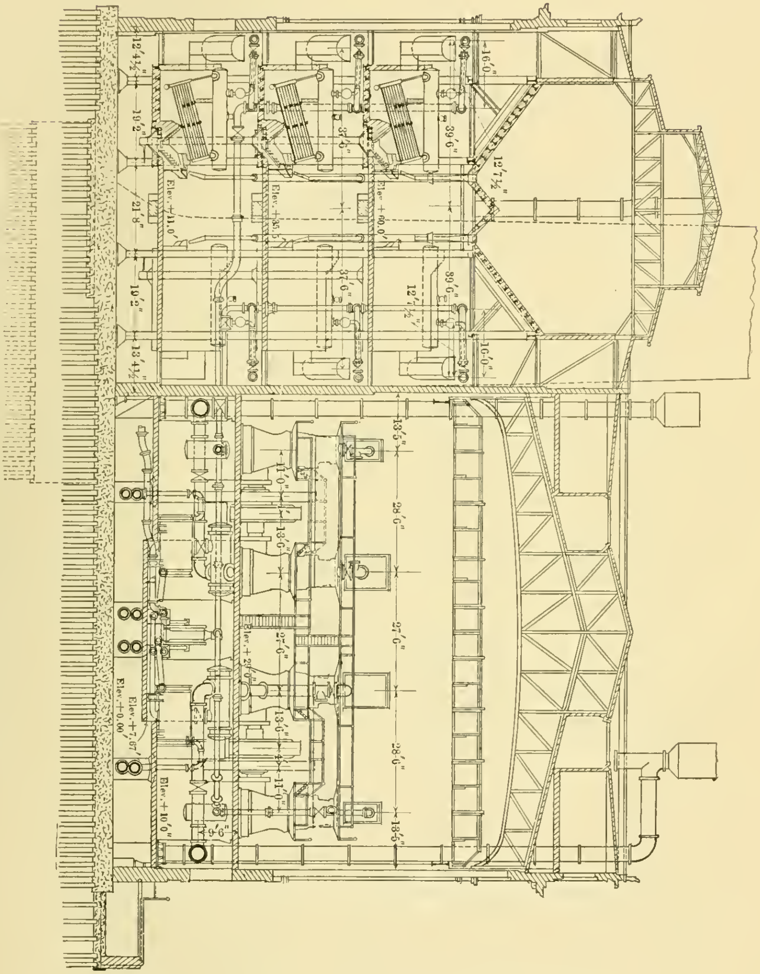
The Engine House.—The engine house has a sub-floor at Elevation + 10, the engine floor being at Elevation + 29. At the west end there is a series of floors at Elevations + 54, + 77 and + 91. These are 22 ft. wide, and are to be used as switch-board galleries. At the top there is a pent house running around on the four sides of the engine house at Elevation + 102.

The engine house has large headroom, and is trussed across by heavy steel trusses 22 ft. 8 ins. apart. These carry a lantern in the center and the pent house on either side.

At the switch-board end, at one corner, there is an elevator and stairway for visitors. At the other corner of the switch-board galleries a spiral stairway is provided especially for the use of the employees. At the other end of the engine house, and in one corner, there is an elevator and stairway in a brick enclosure running up to the pent house and storeroom, with doors to the engine house floor and each successive floor of the boiler house.

Chimney.—The internal diameter of the chimney is 22 ft., and its height is 353 ft. It is higher than any chimney in this country, and of larger diameter than any in the world. It was built the summer before the building, except the foundation walls. In order to keep at work as many bricklayers as possible, it was built from both inside and outside scaffolds, up to a height of 125 ft., and two material elevators were used. From that elevation to the top a scaffold and elevator was carried on the inside only.

It is built mostly of common brick and contains a lining of fire-brick extending about 50 ft. above the highest flue opening. It has two shells. The inner is just thick enough to support its own weight, including the fire-brick lining; the outer carries its own weight and the horizontal wind load, taken at 50 lbs. per foot. To resist this overturning moment, and to stiffen the outer shell, counterforts or



CROSS-SECTION OF POWER STATION LOOKING WEST.

Fig. 4.

ribs were built into it, as shown in Fig. 5. These reach within about 2 ins. of the inner shell and form a guide for its movement by expansion or contraction. The capacity of the chimney was figured by Rankine's formulas. Brick was used instead of steel because masonry is the more durable material. The chimney was carried high in order to avoid the use of exhaust fans or blowers, and because it was thought better to let the foul gases escape at as high a level as possible. It contains about 3 400 000 brick, and rests on a block of concrete 20 ft. thick and 88 ft. square.

The flues enter from opposite sides on each of the three floors, and a baffle wall in the center, reaching just above the highest flue opening, directs the gases upward and prevents the discharge from one side tending to choke up the opposite flue.

The chimney is surmounted by an iron cap, cast in sections and bolted together (Fig. 6). The whole is topped by a series of lightning rods, which are grounded by copper ribbons on opposite sides.

Fig. 1, Plate XXVI, shows the excavation for the chimney, partly filled with concrete, and also shows some of the concrete for the surrounding foundations. Fig. 1, Plate XXVII, is a view of the chimney showing the height to which the outer scaffolding was carried.

The Building.—The building is of brick. The outside is faced with iron-speckled brown brick and is trimmed with granite and with brown fire-flashed terra cotta. The window frames are of iron, and the cornice and monitor trimmings are of copper. Fig. 2, Plate XXVII, is a view of the completed building, from the river end. The inside walls of the engine room are of common brick, but there is a wainscoting of enameled brick up to about 9 ft. above the floor. The walls are for the most part self-supporting. The floors, floor loads, roof, roof loads, boilers, coal pocket and contents are carried by the columns. There is a heavy cornice of terra cotta blocks near the top of the building and this is partially supported and anchored by iron frames, but these are so constructed as to allow a slip down of 1 in. if the wall below should shrink or settle away that much from the iron frame of the building. Other mouldings, cornices, etc., are built into and supported entirely by the walls. Fig. 2, Plate XXVII, shows the ironwork of the building during erection.

The floor loads allowed are as follows: Engine-room floor, 400 lbs. per square foot on the part between the engines, and 600 lbs. in front,

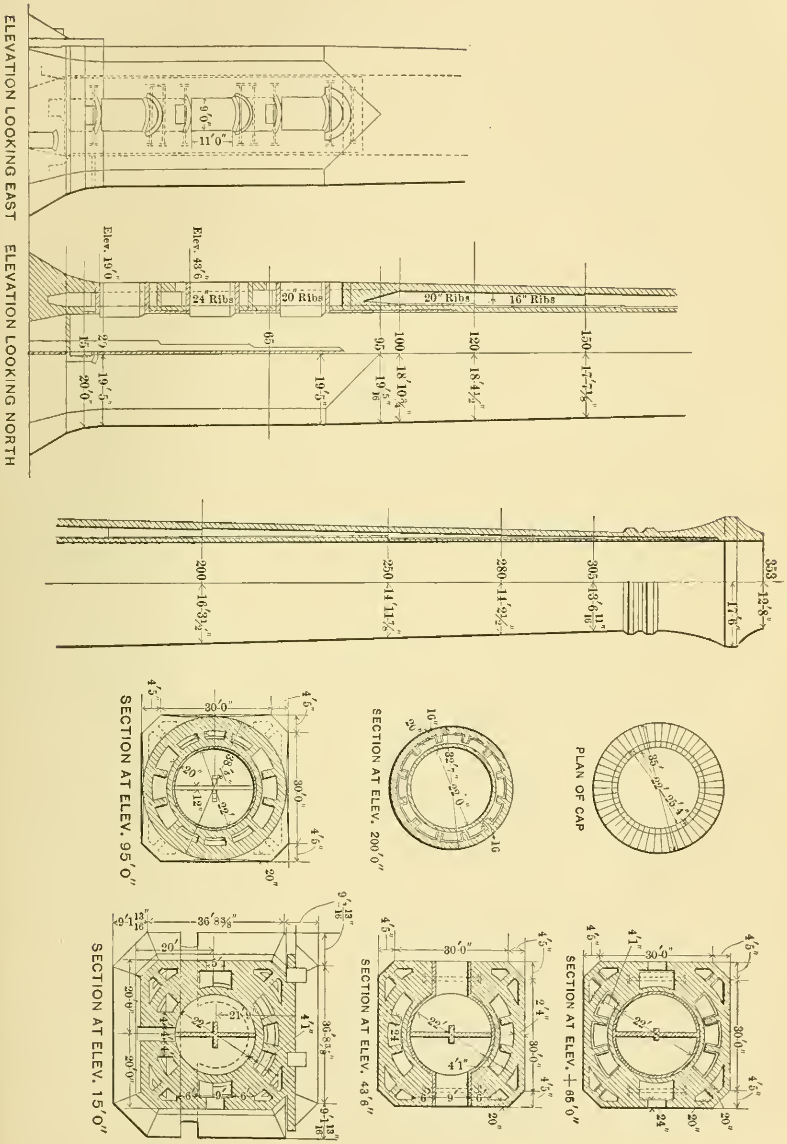

ELEVATION LOOKING EAST
ELEVATION LOOKING NORTH
Elev. 19′0″
Elev. 43′6″
24″ Ribs
20″ Ribs
20″ Ribs
16″ Ribs
9′0″
11′0″
15
27
65
95
100
120
150
200
250
280
305
353
20′0″
19′5″
19′5″
19′5/16″
18′10¾″
18′4½″
17′7⅞″
16′3½″
14′11⅞″
14′2½″
13′6 11/16″
17′6″
12′8″
SECTION AT ELEV. 95′0″
SECTION AT ELEV. 200′0″
PLAN OF CAP
SECTION AT ELEV. 15′0″
SECTION AT ELEV. 43′6″
SECTION AT ELEV. + 65′0″
30′0″
4′5″
20″
22′
32′7″
22′0″
35′
25′4″
36′8⅜″
9′1 13/16″
20′0″
21′9″
4′1″
24″
2′4″

FIG. 5.

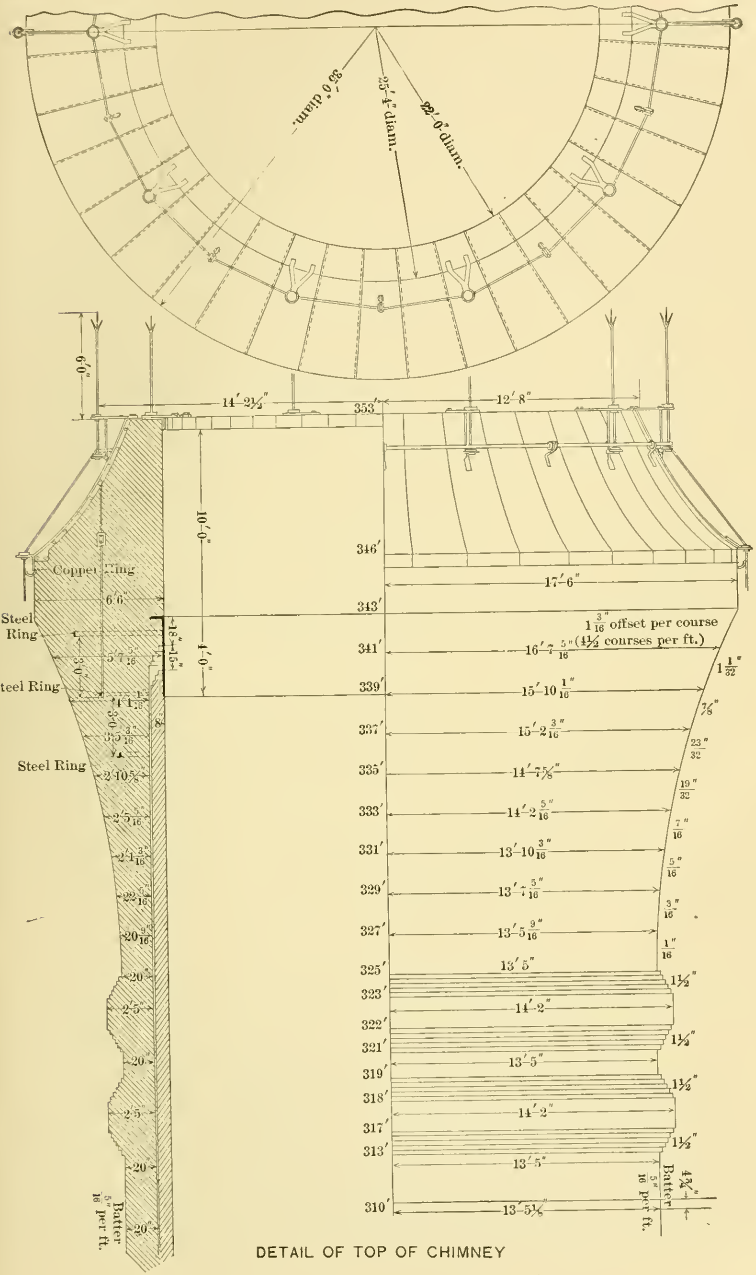
which amply allows for the concentrated loads of the exciter engines and exciter switch-board; sub-engine room floor, 225 lbs. between the engines, with special provision for condensers, heaters and pumps; and 600 lbs. in front where are supported the transformers and rotary converters for a sub-station for the power-house locality; 225 lbs. per square foot on each switch-board floor; 175 lbs. on the pent-house floor; 100 lbs. for the roof; 425 lbs. on the boiler-house floors for the part in front of the boilers; and 225 lbs. for the space between and back of the boilers. These figures include the allowance for the floor itself and for the superficial loads.

No provision was made for longitudinal expansion, as it was considered that it would act each way, from the big brick chimney as a fixed point, and take care of itself. The boiler-house joints are mostly bolted at the bottom, so as to absorb some of the expansion, and are solidly riveted at the top. For lateral expansion the engine-house roof trusses are hung on end pins to allow for any slight movement north from the boiler house, which is rigidly held. The engine-house columns are very long, and those on the north side are wide enough and strong enough to resist the vertical load as well as the horizontal outside wind load.

The wind load was taken at 30 lbs. per square foot at the top, and was decreased somewhat toward the bottom. The columns were made strong enough to resist this wind pressure on a span extending from the end truss pin to the ground, as it was anticipated that the engine floor and sub-floor would not be put in until some time after the building was erected. On the south side of the engine room, the columns are of the same outline, but of considerably lighter metal, as they will have no wind load to resist. The engine-room trusses are pin-connected along the bottom chord and riveted at the top. They carry not only the roof and its load, but also the pent house and its load.

The wind pressure from the east or west is resisted in the engine room by a lateral system in every other bay. This starts in the roof and is carried down to the column bases by diagonal rods and lateral braces. The traveling crane girder, engine-room floor girder, etc., are incorporated with this system.

In the boiler house the columns carry not only the floors and the boilers, but also the coal pockets and, in addition, the roof and its load.



DETAIL OF TOP OF CHIMNEY

FIG. 6.

Each pair of columns in the center of a battery is braced diagonally from floor to floor from the coal pocket down.

The large coal pockets presented quite a problem. The tendency to burst or spread out is resisted entirely from the outside, there being no exposed iron whatever in them. The pockets are lined with I-beams spaced 2 ft. or more apart and varying in depth from 10 to 15 ins. These are filled in with concrete which is carried to about 3 ins. over their tops and then covered with a waterproofing material. The concrete surface was left fairly rough in order to prevent the waterproofing from sliding, or peeling off. The section of the pockets is shown on the cross-section of the building, Fig. 4, and the ends are vertical.

The pressures, of course, are calculated for a maximum load, the conditions for which are that the pockets shall hold as much as they can be made to by trimming, that is, that the coal should slope up from the tops of the vertical sides at the angle of repose to the summit. The pockets can be filled by the conveyors almost to this limiting line.

The pressures on the vertical surfaces were calculated by Rankine's formula for a retaining wall with superimposed loads:

$$p = wx \cos \phi$$

in which p = pressure on a unit of surface,

w = the weight of a unit of volume of the material,

x = the depth below the top of this unit of surface,

$\cos \phi$ = the angle of repose of the material, or the angle of the top slope.

The pressure is parallel to the surface of the material. Then the total pressure on a vertical surface is

$$P = \left(\frac{d_1^2 - d_2^2}{2}\right) w \cos \phi$$

where d_2 = the depth of the top of the surface, and

d_1 = the depth of the bottom of the surface below that point in the top surface of the material directly over the surface.

The weight of a cubic foot of coal was assumed at 56 lbs.

The pressures on the inclined side portions were obtained by considering each surface as composed of a series of steps, and assuming the pressure on the slope to be the resultant of the vertical dead load multiplied by $\cos \phi$ on the horizontal part of each step, and the thrust on the vertical part as calculated by Rankine's formula.

The calculated pressures on the vertical faces of these steps were reduced when the so-called line of maximum pressure—that is, the line bisecting the angle between the vertical and the slope of repose—cuts beyond the crest of the coal slopes; that is, intersects the opposite receding slope, or that slope produced, first instead of the rising slope, and by the amount that the part *B C* (Fig. 7) of the line between the opposite receding slope at *B* and the ascending slope at *C* produced, bears to the whole line, up to the ascending slope line produced, or *A C*.

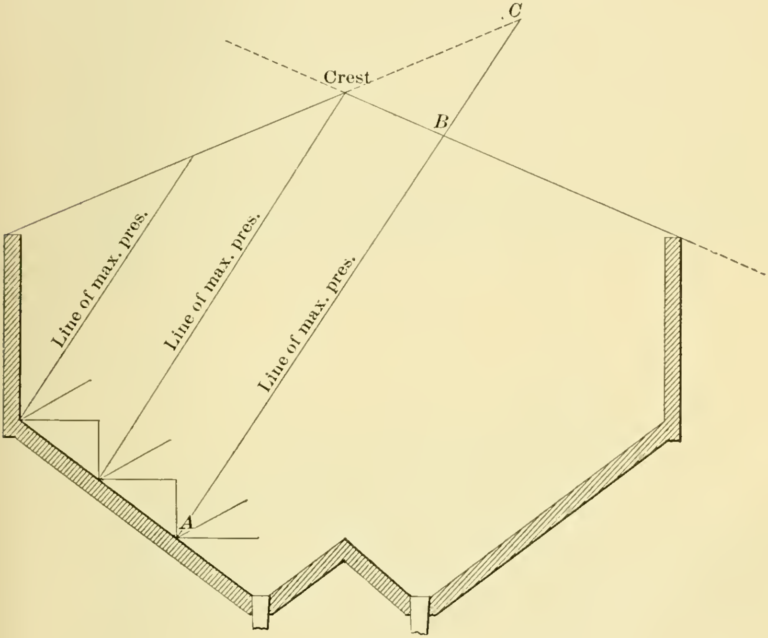


FIG. 7.

In the bottom of the pocket, the two slopes of the crown piece counteracted each other, and therefore it was only necessary to make the V-pieces strong enough to resist this pressure, and the main cross girder only strong enough to bear the vertical load and the tension induced by the side pressures. At the height where the bottom of the vertical portion meets the top of the inclined part there is a horizontal trussing, made strong enough to carry a large portion of the lateral thrust to the corners, and the corners are made strong enough to resist a powerful distorting force.

Across the end of this level there are horizontal trusses strong enough to take the entire end thrust to the corners and thence down the sides where it will be taken up by the frictional resistance of the coal, or, if the pocket is full, it will be partially resisted by the opposite end pressure transmitted along the side pieces.

This was done to provide against any possible bursting tendency of a sudden settlement, one-sided load, or other cause; even for the remote possibility of a slight earthquake.

The strains on the steel, and the loads on the columns and brick work were made to agree with those allowed by the Building Department of New York City by the law used in 1898, before the present law went into effect.

Erection and Cost.—The building excavation was sheet-piled all around because the surrounding material was too soft to take any reasonable slope naturally. The ground-water was easily kept down with one 3-in. and one 6-in. pulsometer, although to do this it was necessary to drive two rows of sheet piling and puddle between them where the cribs running east and west passed out from under the building to the bulkhead. The sheet piling was 3 x 12 ins.

For the chimney foundation a row of 10 x 12-in. tongued and grooved sticks was driven around it in the form of a square. The enclosed space was then excavated to the required depth. The corners were well braced and the piles were driven from the surrounding cellar bottom by attaching to the regular pile drivers sticks corresponding to ordinary derrick booms, and hanging to their ends pairs of ways reaching to the bottom of the chimney excavation. In these ways the hammers were moved and the piles were driven. By this method it was possible to keep several machines at work on the somewhat limited area, and the bother and expense of lowering a machine into the hole and lifting it out again was avoided. The sidewalk vault was excavated and built after the building was nearly finished. The shoring for the earth outside was braced against the building.

Much of the iron-work was erected with house derricks and those of the ordinary form, but the engine-house roof required quite an extensive traveler. At one side it was supported on the tops of the engine foundations and at the other it was at first built on high blocking, and, after two spans (or one bay) of the engine room were up, it

PLATE XXVI.
PAPERS AM. SOC. C. E.
AUGUST, 1900.
MONTONY ON 96TH STREET POWER STATION.

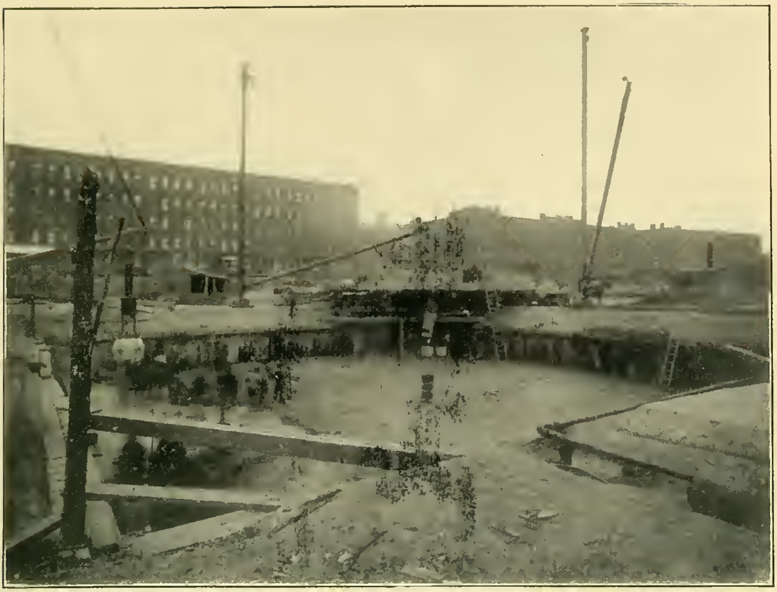


FIG. 1.—CHIMNEY EXCAVATION AND CONCRETE FOUNDATIONS.

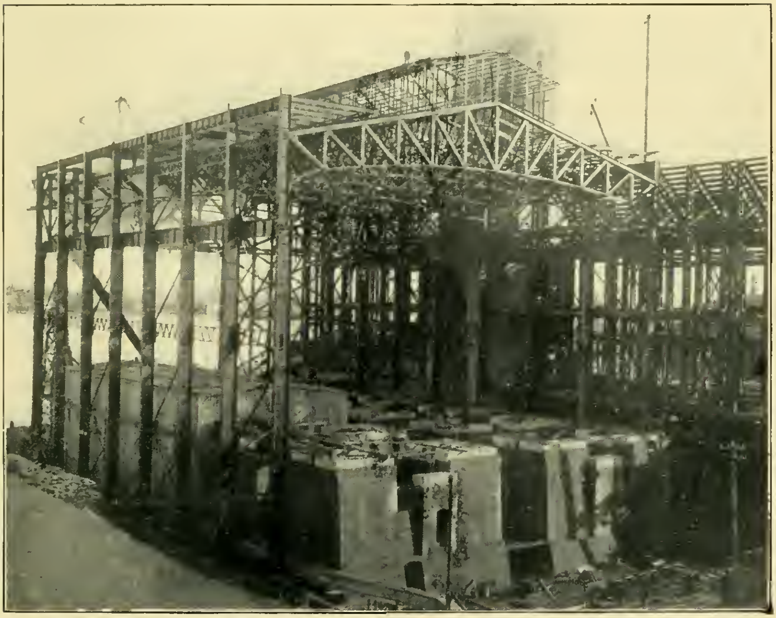


FIG. 2.—FOUNDATIONS OF ENGINES, AND FRAMEWORK OF BUILDING.

was allowed to run on that side on the main-crane girder, on account of the temporary engine house being in the way.

So that the erection of the engines might proceed before the engine-room roof proper was put on, a temporary roof was suspended from the trusses in the two bays of the engine room over engines Nos. 1 and 2.

The intake pit for the circulating water was made by driving 10 x 12-in. tongued and grooved sticks around on its four sides and using these for its walls, both supporting and retaining.

The roof load is distributed on these sheet piles by framing the roof beams into a heavy beam running continuously along the wall. The sheet piles are cut off so low that, while they are not below tide-water, capillarity will keep them wet and reduce decay to a minimum.

To receive the large engines and generators a runway was built on a level with the engine-room floor from the bulkhead to an opening left in the wall; so that, after a single movement from the lighter to the runway, by means of a floating derrick, the parts could be rolled within reach of the large traveling crane.

Cracks in masonry seem to be unavoidable, and two small ones, running from the flue opening upward for a short distance, developed in the chimney, immediately after it was put in use. These have not increased in size, and there have been no settlement cracks in the building, chimney, or machinery foundations.

The excavation, of which there were about 25 000 cu. yds., cost about $1.20 per yard. About 8 000 piles were used. The 35-ft. piles cost $5.50 apiece, and the 45-ft. piles under the chimney cost $7.50 apiece, driven. The concrete used was a mixture of 1 part cement, 2 parts sand and 4 parts broken stone, and cost $5.00 or $4.50 per cubic yard, according to whether American Portland or Rosendale cement was used. The former was used in the foundation concrete and the latter above Elevation + 0. The chimney, above the elevation where the brickwork commences, cost $20.50 per thousand for everything, including damper ironwork, cap, lightning rods, etc.

About 4 000 tons of iron were used for the building, including architectural cast-iron as well as structural work. The total cost of the station, including machinery, will not be far from $3 000 000.

The foundations were put in during the summer and fall of 1897. In 1898 a temporary engine house, shown in Fig. 1, Plate XXVII, was built inside the proposed permanent one, and several boilers were erected on the first floor of the boiler house and temporarily closed in. These gave an electric power of 1 700 K.-W. for about a year before the permanent plant was put in operation.

The chimney and engine foundations were also put in during 1898. In 1899 the building was erected, and during that year the plant was pretty completely equipped.

Engines, Generators, Etc.—In the engine room there are eleven large vertical cross-compound engines, each directly connected to a three-phase alternating current generator in the center between the cylinders. The engines are piped so that either cylinder may be operated alone, and in that case each is capable of generating 4 500 H.-P., maximum. The engines are each of 4 200 H.-P. normal, and of 6 600 H.-P. maximum, capacity. Each generator has a capacity of 3 500 K.-W., and is capable of carrying a 50% overload for a short time.

For a medium-sized cross-compound engine it is quite customary to ship the shaft, cranks, fly-wheel hub and generator hub in one assembled piece. This was deemed inadvisable in this case, on account of the great size and weight of the pieces and the difficulty of moving them. The pieces were, accordingly, shipped separately, the largest pieces being the shafts, which weighed about 35 tons. Each shaft and the pieces pertaining to it were assembled near their foundation, the different parts being forced on the shaft by means of a hydraulic pressure of over 300 tons.*

The shaft is a large hollow forging of 37 ins. maximum diameter, the hole being 16 ins. in diameter. The cranks are of the style known as fan-tail, in distinction from disc cranks or the ordinary unbalanced cranks.

The cylinders are 46 and 86 ins. in diameter, the stroke is 60 ins. and the number of revolutions is 75 per minute. The fly wheels have a rim speed of 6 600 ft. per minute. They are built up; the hub, arms and central third of the rim are of cast steel, and the outer thirds of steel plates. The plates are in thicknesses of 1 in., no two joints come opposite, and they are fastened to the central part and to each other by long 2-in. steel rivets, which were driven cold by hydraulic pressure.* The fly wheels are very heavy in order to absorb quickly the

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* A description of this work can be found in *Power* for August, 1899.

PLATE XXVII.
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MONTONY ON 96TH STREET POWER STATION.

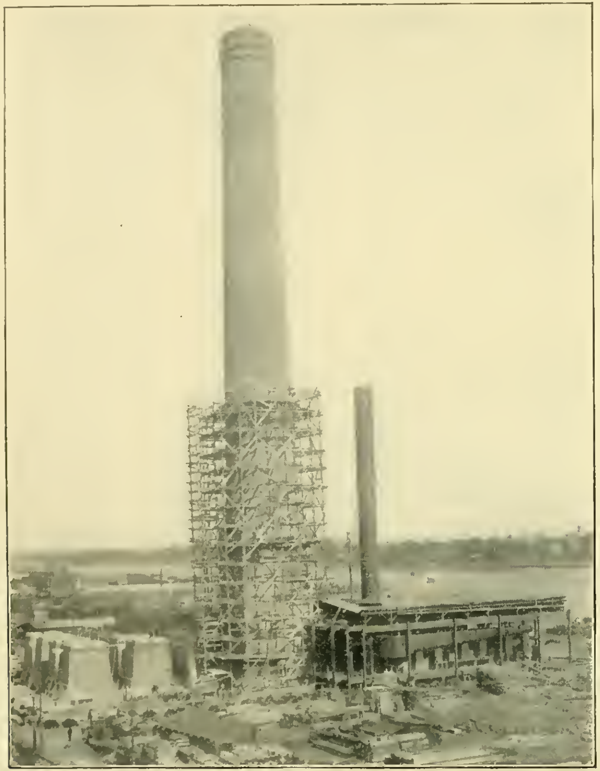


FIG. 1.—CHIMNEY NEARLY COMPLETED, AND TEMPORARY BOILER-HOUSE.

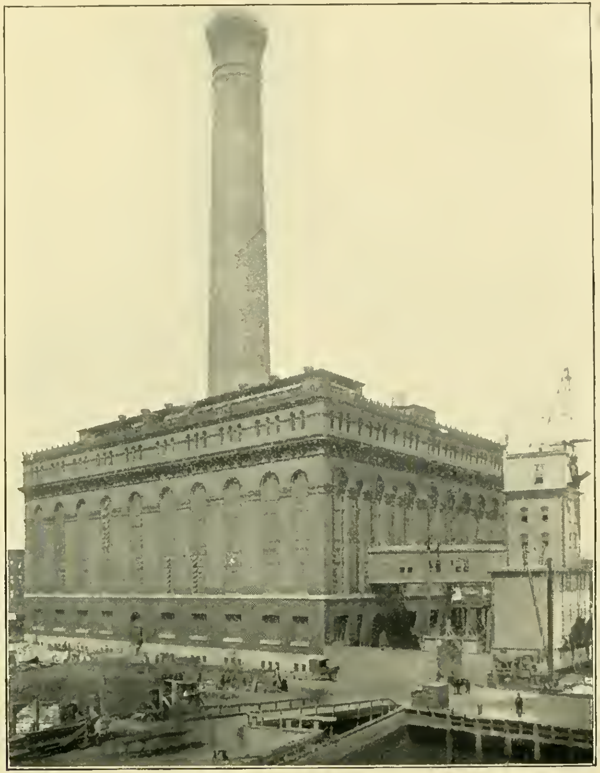


FIG. 2.—VIEW OF THE STATION FROM THE RIVER.

speed variations, for which displacement curves were very carefully calculated.

The valves are of the Reynolds-Corliss type. The valve chambers are cast in the removable heads of each cylinder, and are at the center, a new scheme by Mr. Reynolds, of the Allis Company, by which clearances in the cylinders are reduced.

The connecting rods are of the locomotive pattern, that is, I-shaped instead of round, and the bearings are water-jacketed, as well as piped for the oil supply.

The generators are of the revolving-field type, with fixed outside armatures. The revolving field has 40 poles, and an alternating current of 6 600 volts is generated. The armature was shipped in two pieces and the field in several pieces, as follows: The hub or spider, the rim in four parts, and each pole piece by itself. The armature is of the side-moving type, as made by the General Electric Co., and the pole pieces may be exposed to view without removing the top half of the armature.

The engines stand on the floor at Elevation + 29, and reach about 36 ft. above the floor. Fig. 1, Plate XXVIII, is a view of Engine No. 1, during erection. Fig. 2, Plate XXVIII, shows the interior of the engine room, with eight engines nearly completed.

A separate feed-water heater and condenser is provided for each engine, and is placed in the space under the floor and between the engine foundations. Each condenser has a steam engine driving a single-cylinder circulating water pump and a two-cylinder air pump, the cylinders of which are on either side of and are part of the same frame as the circulating water cylinder. The single steam cylinder is directly over the circulating water cylinder in the center. The exhaust steam from the pumps is so connected that it may be turned into its condenser, into the low-pressure cylinder of its large engine (and thus used expansively), or conducted back into the boiler house to the secondary feed-water heaters.

The exciters are placed at the west end, under the switch-board galleries. Provision has been made here for steam-driven exciters of 60, 30 and 60 H.-P., respectively. The drivers are tandem-compound high-speed steam engines of the "Ideal" make, and are directly connected to small direct-current generators. There is also space for an exciter switch-board and a battery of three electrically-driven exciters, each consisting of a generator coupled to a motor.

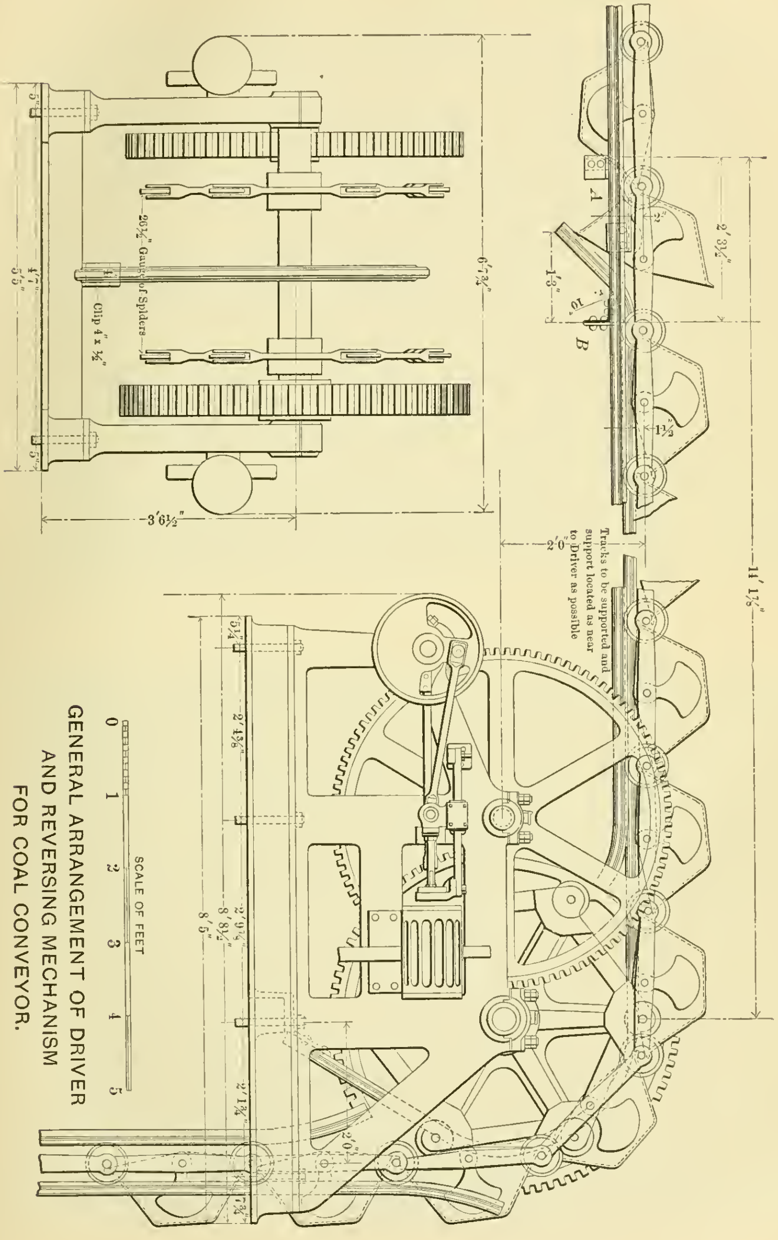
The entire complement of engines has not yet been installed, nor has the third floor of the boiler house been filled. The other engines will be needed if the load of the Third Avenue Railroad is thrown on this station, and the remainder of the third tier of boilers will be filled out with the boilers from the various small electric and cable-driving stations about town, as these stations are discontinued.

The Boilers.—There are 87 boilers, set in three tiers of 29 each. Each boiler is of about 500 H.-P., ordinarily, or 800 H.-P., maximum. These are known as 250 H.-P., ordinarily, when rated by the Philadelphia Centennial Standard, or an evaporation of 30 lbs. of water for 1 H.-P. They are equipped with mechanical stokers, coal chutes to feed them with coal, and ash chutes to convey the ashes to the basement. The stokers are driven through jack-shafts near the tops of the boilers, and the bearings are bracketed out from the columns.

Each line of from 6 to 8 boilers has two small Westinghouse steam engine drivers on platforms between the batteries, the other spaces being planned to be occupied by electric motors. The shafts are propelled by means of link belts. Above the boilers is the coal pocket, divided in half by the chimney, and fed by two link-connected overlapping bucket conveyors, Fig. 8. The total capacity of the double coal pocket is 10 000 tons.

Cranes.—The engine room is provided with several cranes. There is a large three-motor electric crane of 110-ft. span, built by Wm. Sellers & Co., and capable of lifting and carrying 30 tons. An outboard crane feeds the traveler from Exterior Street, and has a hand trolley of 30 tons capacity. A small hand-power crane of 15 tons capacity runs under the first switch-board gallery cross-wise of the building. Another similar one is located directly below it for the sub-station. Provision is also made for a trolley over engine No. 11, and feeding from that to the outboard crane.

Coal and Ash Conveyors.—Coal is unloaded at the wharf by a tower with a fixed horizontal boom, and is transmitted into the pockets by two bucket conveyors. The buckets are 24 x 28 ins., and overlap so as to be continuous-loading without the use of a filler. Sufficient vertical space is provided in the tower for a crusher, if the coal is lumpy, and for two weighing hoppers to be used before the coal is emptied into the conveyors. Each conveyor makes two vertical turns



GENERAL ARRANGEMENT OF DRIVER AND REVERSING MECHANISM FOR COAL CONVEYOR.

Fig. 8.

of 90° and a horizontal twist of about 30 degrees. The length of each conveyor is about 800 ft.

The ashes are picked up from the chutes in the basement and transferred by small trucks on parallel tracks, or by two conveyors, to the river end of the building. Here they are dumped into a vertical bucket conveyor and carried up to the second story where they are again dumped and carried to the ash pocket by the returning coal conveyor. The ash pocket is under the coaling tower, and is about 25 ft. wide and 60 ft. long. It is high enough and of sufficient V-shape to discharge its contents by four chutes into scows at the dock.

Each conveyor is driven by a separate steam hoisting engine. The conveyors are supported from the coaling tower to the building by a steel bridge having a passageway between and on either side of the conveyors. The vertical portions are encased in steel frames, and here the twists are made. The top horizontal parts are supported on the boiler house trusses.

Steam Piping.—The maximum diameter for the mains of the steam pipe system was fixed at 16 ins. on account of the difficulty of placing in position curved lengths of larger size. It is also more difficult to provide expansion for larger sizes and to keep them tight.

At each end of each floor in the boiler house there is a 16-in. loop, and the loops at each end are connected to each other. Each boiler is connected to the line of pipe back of it. Each floor has a connection to each stand pipe, of which there are as many as there are large engines, 11 in all. These are situated near the loops, in the spaces between the batteries of boilers. From the bottom, and below the level of the engine-room floor, a connection runs across to each engine. Before the steam enters the high-pressure cylinder, it goes through a separator. If necessary, steam can be supplied to any engine from any floor of boilers at either end, although, of course, under normal conditions, steam will be taken from the adjacent part of one of the loops.

Any damaged portion of a steam pipe may be cut out by means of valves in the boiler house without cutting out more than one battery of boilers. A leak or break in the engine room would of necessity cut out one engine. There are various small steam pipes for the smaller engines.

The pipe is all of rolled steel with cast-steel fittings. The flanges made of the latter are in part riveted to the pipe and in part connected by the Van Stone patent.

PLATE XXVIII.
PAPERS AM. SOC. C. E.
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MONTONY ON 96TH STREET POWER STATION.

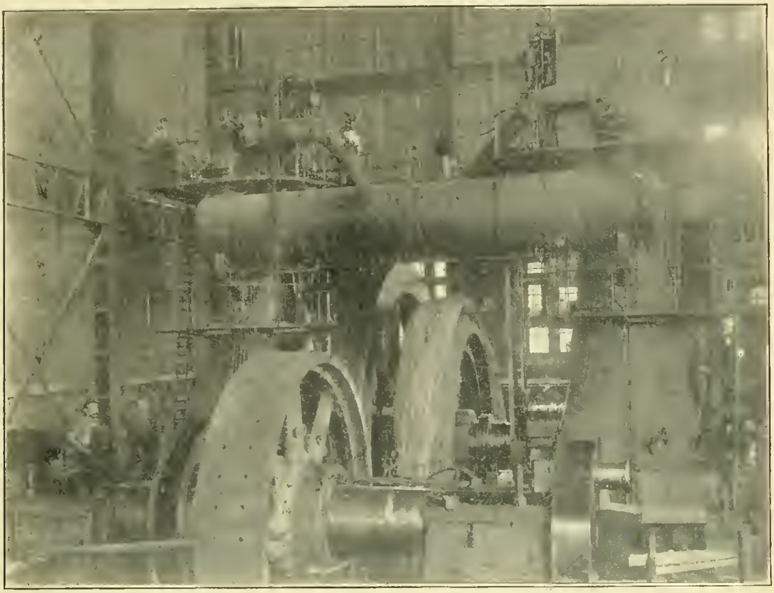

Fig. 1.—Engine No. 1, During Erection.

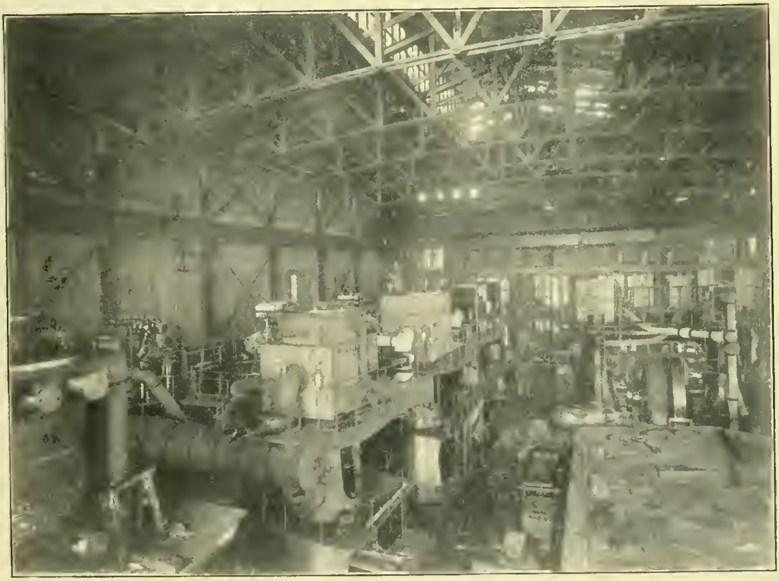

Fig. 2.—The Engine Room.

Exhaust Mains.—Four 42-in. risers are provided for free exhaust, or one for each three engines; and each engine exhaust is provided with a back-pressure valve. In the boiler house there are also smaller exhaust risers as outlets if the exhaust for the feed pumps and auxiliaries is passed through the secondary heaters. The water condensed from each large engine is passed through into its separate hot well where it can settle, become cool and have most of its oily matter removed by a filter at one end. The hot wells are large enough to hold the water for about half a day, if none is passed away and wasted.

Water and Gas Supply.—The water supply is obtained from two separate systems: A main on Second Avenue supplying a section of the city further down town, and a small main supplying the immediate locality. The former connection is on Ninety-fifth Street, is 12 ins. diameter, and is piped to four 6-in. meters. The latter connection is on Ninety-sixth Street, is 6 ins. diameter, and is piped to two 6-in. meters. From the meters the water can go either direct to the feed pumps or to two tanks which may be called equalizing tanks, and in which the water is received from the various sources and mixed or equalized. There is also a 12-in. connection for salt water, which may be used in the feed system if other sources fail, or it may be used for flushing out the basement.

An emergency gas connection will probably be made, so that, if the electric power is absolutely suspended for any reason, the building will not be without light.

Feed-Water.—The feed-water system is provided with three duplex steam-driven plunger-packed compound pumps, of horizontal pattern, and an alternative system consisting of a gang of inspirators capable of elevating a portion of the supply required. The pumps have to work against a pressure of from 160 to 180 lbs.

The feed-water is pumped from the equalizing tanks, or the mains direct, into long mains under the first floor. From these it passes into one or all of the primary heaters in the engine room, or directly into risers which feed through loops into the boilers on the various tiers. From the primary heaters it keeps returning either to the secondary heaters or to the boilers directly. If taken through the secondary heaters it then passes to the boilers. Thus it may take one of the following three courses: To the boilers direct, either at the street temperature, or with that temperature modified by the hot wells; to the primary heaters and then to the boilers at a temperature of about 125°; or, through both the primary and secondary heaters and then to the boilers at a temperature dependent on the number of secondary heaters installed and the amount of exhaust steam turned into them. If a maximum of four were put in, the temperature would be as high as 200°, or not much below the boiling point.

Circulating Water Piping.—The circulating water system consists of four 30-in. suction mains and four 30-in. discharge mains. Each main supplies three large engines. The circulating water is drawn from a basin or well in the vacant space just inside the bulkhead. It is connected with the river by two 42-in. pipes laid through the bulkhead. The discharge mains go out through the bulkhead and discharge into the river. The water drawn in is taken at a much lower level than that at which the discharge is made. The two masses of water at the widely different temperatures are expected to be kept apart sufficiently by this difference in level.

Oil System.—New oil and old oil from the mains is received at the Exterior Street end of the building, near the entrance and in the basement of the engine room. Three duplex pumps are provided to lift the oil up into the oil room. There it can be passed through one or two filters, or taken directly into one of the receiving tanks in that room. From the oil room, at Elevation + 84, the oil is piped to all parts of the large engines, and also to most of the small engines with sufficient head.

Sub-Stations.—Electric sub-stations have been laid out and several have been installed. As soon as these are finished and the cables are removed, the various cable and direct-current electric stations in the city will be gradually abandoned.

The outfit for the sub-stations consists of several rotary converters, their transformers and a couple of blowers to keep the latter cool.

Contractors.—The main features of the engineering work were by the following firms: Most of the structural work was done by the New Jersey Steel and Iron Co., the masonry by M. Reid & Co., the large engines by the E. P. Allis Co., the generators by the General Electric Co., and the boilers by the Babcock & Wilcox Co.

Staff.—Much of the small piping was done by day's work under the direction of the company's engineers, and many small bits of ironwork were let to various firms in the city. The writer had general charge of the plans in the office, and made many of the calculations under the supervision of the Chief Draughtsman, C. E. Corby, Assoc. M. Am. Soc. C. E., and the Chief Engineer, M. G. Starrett, M. Am. Soc. C. E. F. S. Pearson, M. Am. Soc. C. E., was Chief Engineer when the building was commenced; and afterward and up to the present time, Consulting Engineer.

Mr. W. A. Low was the Civil Engineer, and Mr. A. S. Mann the Mechanical Engineer, at the building site, in charge of the work.

Mr. A. V. Porter was the Architect of the building, and Albert Carr, Assoc. M. Am. Soc. C. E., at that time the company's Principal Assistant Engineer, looked after the foundation work for the new building. Mr. W. A. Pearson, Chief Electrician for the company, superintended the wiring and switch-boards, and Mr. R. C. Brown was assistant to Mr. Starrett during the construction of part of the work. All the work was done at the office of the company, except the designing of the engines, generators and other machines. General and special features of these were specified. A large portion of the structural iron-work was designed under the supervision of, and checked by, J. T. N. Hoyt, Assoc. M. Am. Soc. C. E., and the remainder, including the coal pocket, by the writer.

Summary.—The station is unique in the following respects, at least: It is the largest steam-power plant in the world, and generates more power per square foot of ground surface than any other. The power generated is 0.94 H.-P. per square foot as an average, or 1.47 H.-P. as a maximum, for the building only; or 0.70 H.-P. per square foot as an average, or 1.10 H.-P. as a maximum, for the whole property, down to the river.

Everything proceeded smoothly, although somewhat slowly, as is frequently the case with such a large piece of work. Many of the schemes adopted may be criticised, but they were selected after a careful consideration of all available methods. Expense has not been spared. It was the rule to obtain the best, but as cheaply as possible. Considerable attention has been paid to the interior and exterior appearance.

The writer is much indebted to the company for the use of the photographs accompanying this paper, and to Mr. Corby for reviewing the same and advising him of the progress of the work.

Vol. XXVI. AUGUST, 1900. No. 6.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS AND DISCUSSIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

EXPERIMENTS ON THE FLOW OF WATER IN THE SIX-FOOT STEEL AND WOOD PIPE LINE OF THE PIONEER ELECTRIC POWER COMPANY, AT OGDEN, UTAH.

SECOND SERIES.

Discussion.*

By Messrs. DESMOND FITZGERALD and CHARLES W. SHERMAN.

Mr. FitzGerald. DESMOND FITZGERALD, Past-President, Am. Soc. C. E. (by letter).—The writer has yet to see a structure for conveying water which will have the same capacity after it has been some time in service as it had when new. There may be some material which will not change its character, and upon which animal or vegetable life will not grow, but the writer has not met with such material in his experience. It is, however, extremely dangerous to generalize in engineering matters. There are hardly two waters exactly alike in chemical composition, and serious mistakes may be made by applying the results of experience from a soft New England water to a hard, lime-carrying western water. The writer has often been informed that certain structures for conveying water have as large capacity at the end of several years as they had when new, but closer examination has shown that the data were not sufficiently accurate to settle the question.

The experiments made on large pipes, under the direction of the writer, have already been referred to by Mr. Charles W. Sherman, so

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*Continued from May, 1900, *Proceedings*. See February, 1900, *Proceedings*, for paper by Charles D. Marx, M. Am. Soc. C. E.; Charles B. Wing, Assoc. M. Am. Soc. C. E., and Leander M. Hoskins, C. E., on this subject.

Mr. FitzGerald.

that it is unnecessary to say much more in regard to them, except to add that the water was measured carefully by weir, that the losses of head were ascertained from observations on extremely accurate mercury gauges, and that proper corrections were made in working out the results.

The writer has also made experiments on the flow of water through cement-lined pipes, and has been very much surprised to find that there were large frictional losses, almost as great as those arising from old cast-iron pipes, and the only way he can account for this is that even cement-lined pipes do not remain perfectly clean for an indefinite time.

For many years the writer has had charge of the Cochituate and Sudbury Aqueducts and of the determination of their capacities, and he has been very much impressed with the effect on the flow of the water due to slimy growths on the surface of the brickwork. In the case of the Cochituate Aqueduct, if the deposits of slime and dirt are allowed to collect on the interior, they gradually give place to growths of Spongilla, and if these are allowed to accumulate, after a year or two, they become very hard, with long finger-like growths, which are serious obstructions to the flow. With changes of flow, this accumulated dirt on the walls of the aqueduct affects the quality of the water, so that, aside from the question of friction, there is also the important question of the effect on the quality.

In the case of the Sudbury Aqueduct, it has been found that, if the surface of the brick-work is not cleaned, in the course of a year it may accumulate sufficient slime to diminish the maximum capacity about 10 per cent. Some years ago the writer devised a method of cleaning, by a machine which worked under a pressure of water. The machine was carried on wheels with wooden tires, was provided with rotary brushes for cleaning the sides and bottom of the aqueduct, and worked very effectively. A movable shield in front held the water back so as to give the power. The machine was arranged to clean to a height of about 4 ft. only, and since it has become necessary to run larger quantities of water in the aqueduct, the machine has been taken out, and the whole length is now cleaned by hand. This is accomplished by a number of gangs of men, provided with rubber boots, stable and rattan brooms, and reflectors. It takes about nineteen men to clean a mile of aqueduct in a day.

Current meter observations have been taken on the flow in the Sudbury Aqueduct, and the results have been extremely accurate and satisfactory. On April 4th, 1899, with a flow of 74 000 000 galls. daily, the capacity of the aqueduct was only 92.58% of the tabulated capacity, and after cleaning on May 29th, at which time 95 000 000 galls. per day were flowing, the capacity was 103.95% of the tabulated capacity. It is possible that, where an aqueduct has been for a long

Mr. FitzGerald. time in use without cleaning, this decrease in carrying capacity may be found to be even greater than 10 per cent. The writer believes that the facts just cited are sufficient to demonstrate the commercial advantages, under some conditions, of keeping an aqueduct clean, as, for instance, when its full capacity is liable to be taxed.

Mr. Kuichling states that vegetable and animal growths are not often found on the bottoms of pipes, and this agrees with the observations of the writer, but the latter has seen the invert of the Sudbury Aqueduct almost completely covered with a thick growth of sponge.

Mr. Meem has stated that "This doubtless shows that organisms require more, as Mr. Whipple suggests, than that their food be brought to them, and they must also have a 'lodging place,' which is probably furnished in the steel and iron pipes by the commencement of rust." In connection with this matter, the writer desires to state, that the growths all around the interior of the new cast-iron pipes already alluded to, were in the nature of a greasy scum, and, that when this was washed off, the coating of the pipe underneath was as bright as when first laid.

The writer recently had occasion to lay a cast-iron pipe having a diameter of 61½ ins., and 1 800 ft. in length, as an inverted siphon. The reason for using this odd size was that it was found more economical to use the outside moulds already prepared for making a thick 5-ft. pipe, and to produce the thinner pipe, desired for the light pressures at the siphon, by increasing the size of the core. Every effort was made to lay this pipe with great care and to make very tight joints. Under careful test the leakage was found to average only 12 galls. per day for the whole length of the pipe, or 0.005 gall. per day per foot of joint. The interior portions of the joints were filled with Portland cement flush with the pipe and finished very smooth. The pipe was also given an extra painting. In this connection, it may be interesting to note that the average leakage per day per foot of joint from the 48-in. distribution pipes recently laid by the Metropolitan Water-Works was about 5 galls. per day per foot of joint.

The results of some experiments made to determine the carrying capacity of this siphon pipe gave a value of "*c*" in the Chezy formula of 149.6 for a velocity of 4.65 ft. per second and 154.3 for a velocity of 6.51 ft. per second. The writer believes that this coefficient, 154.3, is the highest ever recorded for cast-iron pipe, but there is no doubt in his mind that in the course of about twenty years this will be reduced by tuberculation to 100.

Mr. Sherman. Charles W. Sherman, Assoc. M. Am. Soc. C. E. (by letter).—The writer is very glad that Professor Williams has drawn attention to the necessity for some criterion other than the reputation of the experimenter, and the apparent accuracy as indicated by the method

Mr. Sherman.

of least squares, to give some indication of the reliability of experiments. The method used by Professor Williams and Mr. Fenkell is, doubtless, of great value, as indicating what experiments of any series should be rejected. It involves, however, both a needless assumption and an unnecessary amount of work in its application. If the logarithms of the velocities be plotted as abscissas, with the logarithms of losses of head as ordinates, a straight line can then be drawn to represent the plotted points, without the laborious computation of, or even the necessity of taking from a diagram, the values of $\frac{v^2}{2g}$, or the "velocity head." By the use of logarithmic cross-section paper, this plotting can be done with great rapidity.

An especial advantage of this method is that it does not require the assumption that the loss of head varies as the square of the velocity: It is assumed only that this loss varies as some unknown power of the velocity. The criterion, that is, the comparison of plotted points with the line representing the series, is similar to that proposed by Professor Williams.

This application of the logarithmic diagram is not new. As far as the writer knows, it was first introduced to this Society by Desmond FitzGerald, M. Am. Soc. C. E., in his paper on "Flow of Water in 48-In. Pipes."* Mr. FitzGerald refers to a paper before the Royal Society for the origin of this method. To be sure, it is not there noted particularly that this furnishes a criterion for the acceptance or rejection of particular experiments in a series, as the method is used in the derivation of an exponential formula. The advantage of the logarithmic diagram over that obtained by plotting "velocity heads" can, perhaps, be expressed no better than in Mr. FitzGerald's words, "Resistances do not vary exactly as the square of the velocity, however much the text books may insist to the contrary."

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* *Transactions*, Am. Soc. C. E., Vol. xxxv, p. 241.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

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PAPERS AND DISCUSSIONS.

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ON THE FLOW OF WATER OVER DAMS.

Discussion.*

By Messrs. E. KUICHLING, E. A. FUERTES, ROBERT E. HORTON, WALTER C. PARMLEY and GEORGE T. NELLES.

Mr. Kuichling. E. KUICHLING, M. Am. Soc. C. E.—This paper may fairly be regarded as a useful contribution to the literature of hydraulics, as it gives us a translation of Bazin's summary of his recent experiments on the flow of water over weirs and dams of various section, along with data obtained at the Hydraulic Laboratory of Cornell University relating to the flow over a number of dams, of both larger and different section from those used by Bazin, and under much greater heads. The method of conducting the experiments at said laboratory appears to have been similar in general to that which was followed by Bazin, except that no direct volumetric determinations of the discharge were made, as no facilities for this purpose are yet available there. On this account the calibration of the large standard reference weir could be done only by assuming the accuracy of some one of the various existing weir formulas; and, as Bazin's formula was not only the most recent one, but also purported to consider fully the influence of the height p of the standard weir above the bottom of the channel of approach, it was accordingly selected by the author as best representing the law of discharge.

Owing to the various algebraic errors in the paper as originally submitted, it becomes proper to state here that the correct form of

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* Continued from May, 1900, *Proceedings*. See March, 1900, *Proceedings*, for paper by George W. Rafter, M. Am. Soc. C. E., on this subject.

Mr. Kuichling.

Bazin's preferred formula, adapted to measures in English feet, for the flow over a sharp-crested vertical weir with end contractions suppressed, is:

$Q = m\, l\, h \sqrt{2\, g\, h}$, where the coefficient

$$m = \left\{ \left(0.405 + \frac{0.00984}{h}\right) \left[1 + 0.55 \left(\frac{h}{p + h}\right)^2\right] \right\},$$

and h is the observed head or depth of the water above the crest, measured at a distance of 5 m., or 16.4 ft., above the weir, while p is the height of the horizontal weir crest above the bottom of the channel, and l is the length of said crest or the width of the channel of approach, which is assumed to be of uniform section, with vertical sides and horizontal bottom. An apparatus of this description is called a standard weir when provision is made for the free admission of air under the falling sheet of water.

It should also be remembered that this formula was established from comparative experiments with standard weirs of different length and height, within a rather limited range and with comparatively low heads. Bazin's largest weir was only 6.56 ft. long and 3.72 ft. high, on which a maximum head of about 1.0 ft. was used, on account of restricted volumetric capacity. For heads from 1.00 to 1.32 ft. it was necessary for him to reduce the length of this weir one-half, or to 3.28 ft.; and for heads from 1.32 to 1.77 ft., the latter length was again reduced one-half, or to 1.64 ft., while the height was reduced to 3.30 ft. In reference to the experiments made with the last-mentioned weir, Bazin states that as it was possible for the retardation by friction against the side walls to become appreciable in so small a weir or channel, the observations made therewith were used by him only to deduce the law of increase of the coefficient m for heads greater than 1.32 ft., whereas the more numerous and precise results furnished by the two longer weirs served as the basis for determining the discharge of the standard weir. The computed values of the coefficient m for said longer weirs under the same heads up to 1.00 ft. were found to agree quite closely, whence Bazin inferred that for moderate values of h the law of the discharge $q = \frac{Q}{l}$ per unit of length of the weir was not materially affected by the length l, provided that the same was more than 3.0 ft., and that the curve obtained by plotting the values of m as ordinates to the corresponding values of h as abscissas could fairly be extended from $h = 1.00$ ft. to $h = 2.0$ ft., governed somewhat in shape by the curve for m given by the shortest weir.

Furthermore, to find the effect of varying the height p of a standard weir, Bazin next compared the heads h for known discharges Q over his longest weir, having $l = 6.56$ ft. and $p = 3.72$ ft., with those which were observed for the same discharges over four secondary standard weirs of the same length l, but having heights of

Mr. Kuichling. 2.46, 1.64, 1.15 and 0.78 ft.; and he also computed and plotted the values of m for each series of experiments corresponding to the different values of h. The latter, however, did not exceed $h = 1.48$ ft. on the standard reference weir having $p = 3.72$ ft. Within these limits of head and height, and the same length l, it was found that the values of the coefficient m derived from experiment did not vary more than 1% from those given by the aforesaid expression:

$$m = \left\{ \left(0.405 + \frac{0.00984}{h}\right)\left[1 + 0.55\left(\frac{h}{p+h}\right)^2\right] \right\}$$

except in the case of the lowest weir, were the value of m for small heads given by the formula is about 2% more than found by experiment, although such excess gradually reduces to zero as the head h increases to 1.30 ft.

Such is the foundation of Bazin's formula for the discharge over standard weirs with suppressed end contractions and heads h measured 16.4 ft. above the crest, and the question now arises whether it can be applied without material error, either to the large standard weir at the Hydraulic Laboratory of Cornell University, where the length $l = 16.0$ ft., the height $p = 13.13$ ft., and the heads h, up to a maximum of 3.0 ft., were measured 10 ft. above the crest, or to the author's secondary standard weir at the same place, where the length $l = 6.53$ ft., the height $p = 5.26$ ft., and the heads h, up to a maximum of 4.874 ft., were measured 37 ft. above the crest.

In the absence of direct experimental evidence, little further can be said on this subject except to quote the remark of the late Hamilton Smith, Jr., M. Am. Soc. C. E., made on page 169 of his classic treatise on hydraulics, in concluding his comparison of the values of the coefficient of discharge for weirs of different length and large heads, that "such speculations, though possibly ingenious and plausible, when tested with facts, generally prove to be very wide of the truth." While this remark was intended to apply to cases far beyond the limits of accurate experiment, it is, nevertheless, also pertinent in some degree where such limits have been considerably exceeded, as in the present case; and hence it will be prudent to suspend judgment about the accuracy of the large discharges until the figures are properly corroborated. Under these circumstances, accordingly it, appears admissible to indulge in a little speculation about Bazin's formula for the coefficient m.

In this formula both the observed head h and the height p of the weir above the bottom of the uniform channel of approach are taken into account, but the width of the channel or the length l of the weir is omitted for the reason already given. Now, while the retardation of the flow by friction on the sides of the channel in the vicinity of the weir may be negligible in the case of long weirs and small

Mr. Kuichling.

heads, or up to a certain limiting ratio $\frac{h}{l}$, it is evident from observations of the relative velocities of thick sheets of water that beyond such limit this lateral friction cannot be disregarded; and hence a rational formula of general applicability should make the value of the coefficient m dependent also upon the channel width or weir length l, thereby allowing the formula for the discharge over a standard weir to pass gradually with reducing value of the height p into that for a uniform channel. This condition is not embraced in Bazin's formula, as will be seen from the following consideration.

When the height p becomes very small relatively to the head h, or disappears entirely, the above formula for m becomes practically $m = 1.55\left(0.405 + \frac{0.00984}{h}\right) = a + \frac{b}{h}$, while that for the discharge Q becomes: $Q = m\ l\ h\ \sqrt{2\,g\,h} = \sqrt{2\,g}\left(a + \frac{b}{h}\right) l h \sqrt{h}$, which should obviously correspond with the formula for the flow in a uniform open channel. Taking for comparison in this case the Chezy formula on account of its simplicity, we will have for the same discharge: $Q = A\ v = A\ c\ \sqrt{r\ s}$; and by replacing the section A by its equivalent $l\ h$ in the nomenclature of the weir formula, and the hydraulic radius r by its equivalent $\frac{l\ h}{l + 2\ h}$, there follows:

$$Q = c\sqrt{\frac{l\ s}{l + 2\ h}}\ .\ l\ h\ \sqrt{h}$$

By equating these two values of Q, which are manifestly alike, we obtain: $\sqrt{2\,g}\left(a + \frac{b}{h}\right) = c\sqrt{\frac{l\ s}{l + 2\ h}}$, which is an entirely incongruous result, being true only for particular values of l, h and s when the value of c is given. The inference is, therefore, justifiable that Bazin's formula can only give correct results in the neighborhood of the experimental limits from which it was derived, and that discordant results will probably be found if it is applied to conditions considerably beyond said limits.

It may also be mentioned that Bazin's expression for m attains a minimum value for a particular value of h with each value of p. By applying the usual mathematical process for maxima and minima to said expression it will be found that for Bazin's standard weir with $p = 3.723$ ft., m will become a minimum $= 0.4245$ for $h = 0.814$ ft.; for the author's experimental standard weir at Cornell University, with $p = 5.26$ ft. m will become a minimum $= 0.4207$ for $h = 1.003$ ft.; and for the large standard weir at the same place m will become a minimum $= 0.4137$ for $h = 1.765$ ft. On comparing these latter values of m, as well as a few other computed values of m for $h =$

Mr. Kuichling. 1.0, 2.0 and 3.0 ft., with those given by the author on Fig. 2, a considerable disagreement will be noticed, whence a numerical error has probably been made in the author's computations. The text also indicates that the said values of m on page 295 refer to the experimental standard weir with $l = 6.53$ ft. and $h = 5.26$ ft.: but on examining the diagram of discharge of the large standard weir with $l = 16.00$ ft. and $p = 13.13$ ft., on page 301, it will be found that the same values of m, or $\frac{Q}{l}$, were used as given on page 295 for the smaller weir; and if such be the case another slight error has been made in the paper. The discrepancies in the values of m just mentioned are exhibited in Table No. 9.

TABLE No. 9.

For observed heads on weir of:	$h =$	1.00	2.00	3.00 ft.
1. Author's values of coefficient m for the experimental standard weir 6.56 ft. long and 5.26 ft. high, are, as per page 295............	$m =$	0.4174	0.4106	0.4094
2. Values of m computed by writer from Bazin's formula for same weir, are..................	$m =$	0.4207	0.4270	0.4379
3. Values of m deduced by writer from Bazin's table in Annales des Ponts et Chaussées, 1888, page 446, for a standard weir 1.60 m., or 5.26 ft. high, are............	$m =$	0.4232	0.4252	Beyond limit of Table.
4. Values of m computed by writer from Bazin's formula with $p = 13.13$ ft., corresponding to large standard weir at Cornell University Laboratory, are................	$m =$	0.4160	0.4139	0.4160

The use of the author's experimental sharp-crested weir, 6.53 ft. long and 5.26 ft. high, has not been made clear in the text. Apparently, it was built for the purpose of calibrating the large standard weir, 16.00 ft. long and 13.13 ft. high, but as the author states explicitly on page 296 that "for the reduction of Experiments Nos. 20 and 21 (referring to said two weirs) a discharge curve was computed for the upper (large) weir for heads up to 1.97 ft., using Bazin's formula," it is not easy to discover its significance unless to find therefrom the comparative values of m for large heads measured at a distance of 37 ft. above its crest. In this event the experimental data would have been of much interest, as they would have established in some degree the truth or error of Bazin's formula when applied to high heads, and it is to be hoped that the author will supplement his paper with such data.

Another point of interest is the matter of the proper distance above the weir or dam at which the head h should be measured, as well as the details of such measurement; but as this part of the subject has been fully considered in the discussion by Gardner S. Williams, M. Am. Soc. C. E., further reference thereto may here be omitted.

Mr. Fuertes.

E. A. Fuertes, M. Am. Soc. C. E.—The remarks of Mr. Williams, upon the lack of methods for performing volumetric measurements at the Hydraulic Laboratory of Cornell University, are pertinent and justifiable; but it must be borne in mind that the laboratory is as yet unfinished. There are, indeed, methods available, on the spot, for more or less accurate and direct volume measurements, but not of the nature intended to be made in the future, and for which, fortunately, topographical conditions lend themselves admirably to measure almost any desired volume of water. So far, this laboratory is a huge engine, with possibilities. Its final suitableness is a question of time and money. The speaker wishes to impress upon engineers the fact that such a laboratory exists; that its resources can be extended unlimitedly, and that one of the methods which will bring us quickly to the desirable conditions of which Mr. Kuichling speaks is to enlist the good offices, the good-will and the aid of the hydraulicians of this country to send us problems to solve, either under our own direction or under the direction of such visiting engineers as may desire to superintend the work.

It seems advisable to say, however, that while Cornell University will do everything that may be possible with its personnel, equipment and other facilities for the progress of hydraulic science, it seems reasonable that such expense as may be necessary and may not be covered by the facilities of the laboratory at the time should be defrayed by the party seeking information. Nothing will be stinted on the part of Cornell University.

Mr. Horton.

Robert E. Horton, Esq. (by letter).—The results of the Cornell experiments and those of Bazin emphasize primarily the necessity of using a variable coefficient in the weir formula, whenever the flow over an irregular-crested dam is to be computed. To facilitate calculations of this character, and thereby make the results of these experiments more readily applicable in practice, the accompanying diagram, Plate XXIX, has been prepared. Having selected the value of the coefficient *C*, required for the given head and section, its value is scaled off on the line of ordinates at the left of the diagram and traced horizontally to its intersection with the transversal corresponding to the head required; the projection of this point of intersection on the line of abscissas will show the flow over the dam in cubic feet per second for one lineal foot of crest, without lateral contractions.

The chief distinction between the experiments made at Cornell University and those of previous experimenters, including Bazin, lies in the fact that the former were made on "life size" dams, as it were, and extended through a much wider range of heads. This is illustrated by Table No. 10, which shows the superior limit of various experiments on flow over sharp-crested weirs.

Mr. Horton.

TABLE No. 10.

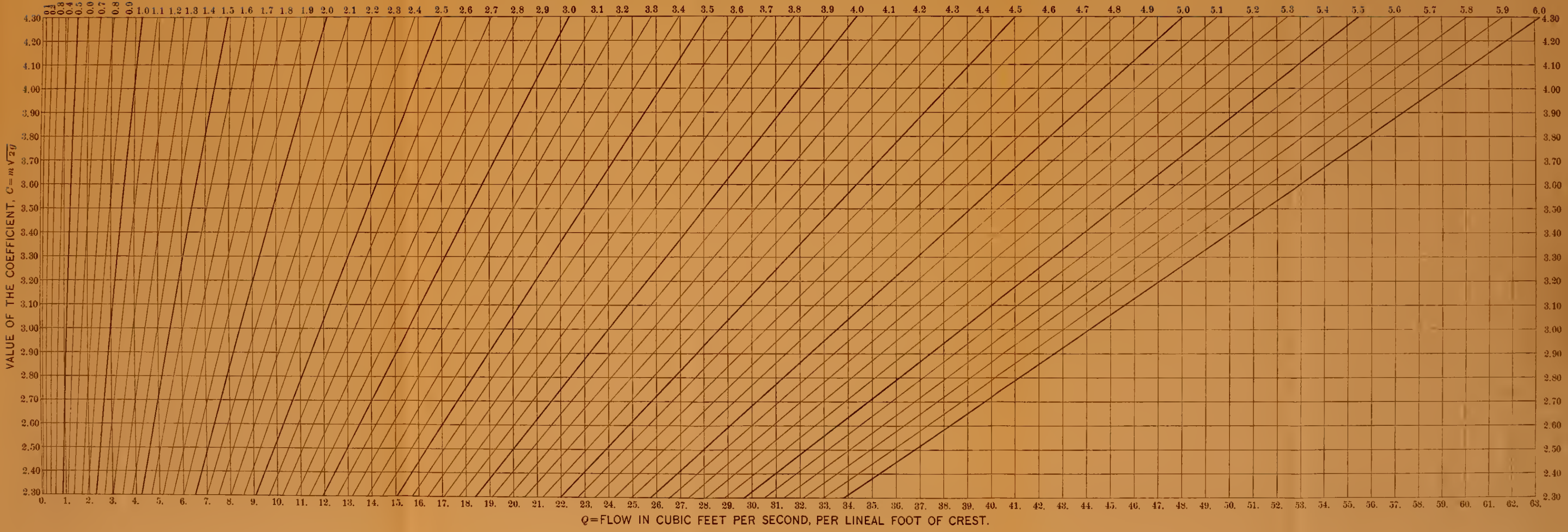
Name of experimenter.	Date.	Limiting head used in experiments, in feet.	Length of crest of experimental weir, in feet.	Distance up stream from weir to point of measuring H, in feet.
Poncelet and Lesbros..	1828	0.682	0.66	11.48
Lesbros................	1834	0.8009	0.6562	11.48
Francis................	1852	1.62	9.995	6.00
Hamilton Smith, Jr...	1874–76	1.7327	2.586	7.6
Fteley and Stearns....	1878	1.6038	19	6.0
Bazin..................	1886	1.77	6.56	16.40
Cornell experiments...	1899	4.672	6.56	38.0

Owing to the limitations pointed out by the author, the Cornell experiments were less elaborate as regards minuteness of detail than were those of Bazin; as a rule, only four or five experimental coefficients were determined as a basis for plotting the mean coefficient curves. Bazin usually obtained twenty or more experimental coefficients, within a much narrower range of variation of head. The advantage of repeating the experiments for small increments of head will not be as great, however, as might at first be imagined, in cases where the species of nappe does not change. In accordance with a well-known law of Least Squares, the precision of the mean coefficient curve will be proportional to the square root of the number of observations it represents. Quadrupling the number for each section would result in dividing the numerical factor for precision by two; moreover, the coefficient for each period in the Cornell University experiments is deduced from the mean of a relatively large number of observed heads on the weirs. This number, being more than twenty in each case, is so great that any moderate increase in the number would not have resulted in a proportional gain in precision. An examination of the coefficient curves will show that, as regards the individual coefficients, they appear no more discordant when plotted than do those of Bazin.

In the design of dams with depths sometimes as great as 12 ft. on their crests, there is a pressing need for data which will apply with a reasonable degree of accuracy. It is to be hoped that the Cornell experiments may be extended by the determination of additional coefficients for intermediate heads, and by experiments on a wider variety of dam sections than was possible at the time these experiments were made. Hitherto, engineers have generally accepted the standard sharp-crested weir as being the most reliable means of measuring relatively small volumes of flowing water. A free nappe, which is neither depressed, adherent, nor wetted underneath, represents the ideal condition, and might be termed a "Standard Nappe." This condition, as has been pointed out by Bazin, is very difficult of attainment. Most of the modifications to which the nappe is subjected

DIAGRAM SHOWING FLOW OVER DAMS,

$Q = CLH^{3/2}$



Mr. Horton.

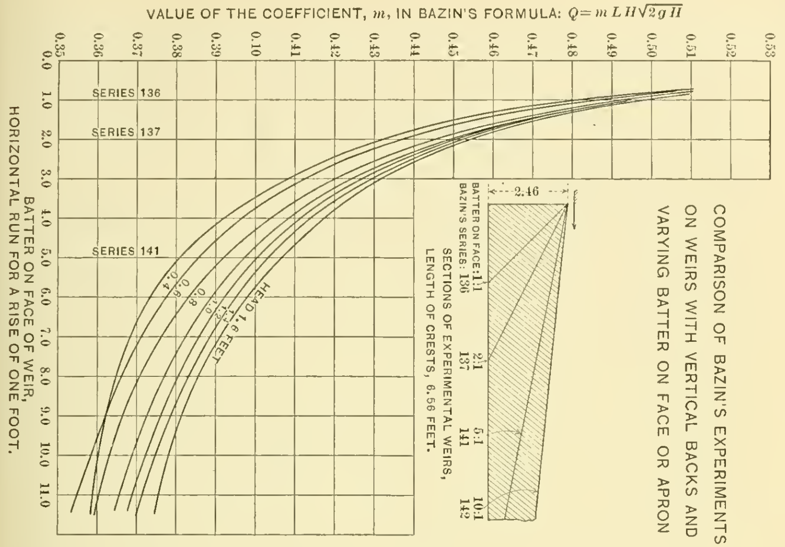


FIG. 22.

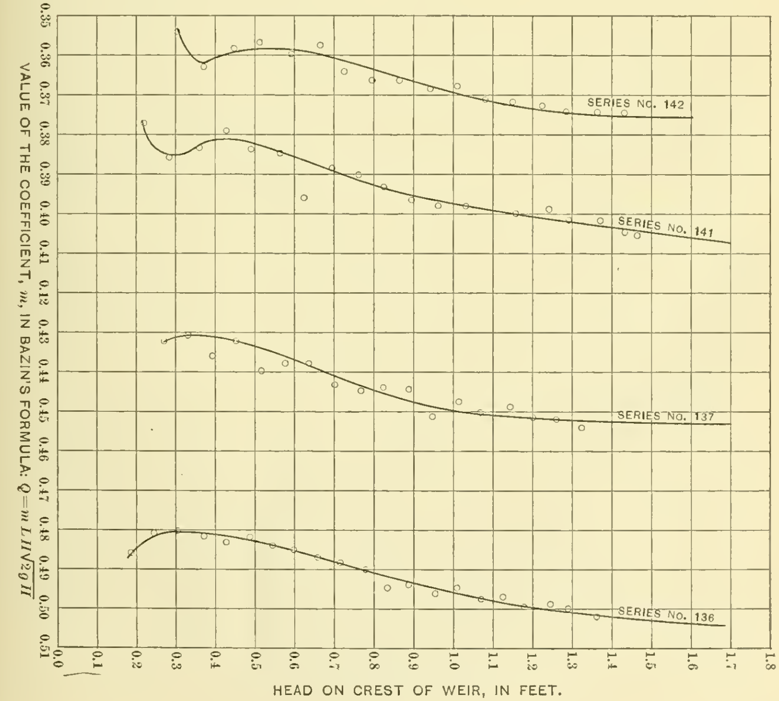


FIG. 23.

Mr. Horton. under different conditions are phenomena belonging to comparatively low heads; for many, if not all, forms of weir sections, the nappe undergoes these various metamorphoses with heads not exceeding from 1 to 2 ft., and then settles down to a stable form which is retained for all higher heads. These facts point to the conclusion that weirs or dams are best adapted for the measurement of large streams of water forming depths of several feet on their crests.

Francis did not experiment with depths of flow exceeding 1.6 ft., although he computed discharge tables, by means of his formula, for heads up to 3 ft., and, as pointed out by the author, the constant coefficient, 3.33, has commonly been applied for all heads, however great. The formula of Bazin furnishes, perhaps, the most reliable means of determining the flow over low weirs with slight heads, and, in reducing the Cornell experiments, it has been used as a basis for determining the flow over the standard sharp-crested weir. Referring to Fig. 2, it will be seen that, for heads from 1 to 6 ft., the discharge coefficients deduced from the Cornell experiments Nos. 20 and 21, for a standard sharp-crested weir, remain nearly constant, varying only between the limits 3.350 and 3.284. The average value is 3.306, or 0.7% less than the constant value 3.33, assumed by Francis, from a series of experimental coefficients varying from 3.31 to 3.35. Francis' formula, therefore, is practically verified for heads up to the limit of the Cornell experiments, and its reasonable use, for any ordinary head on a sharp-crested weir, appears to be justified.

It is greatly to be regretted that Bazin's experiments were not conducted on such a scale as to make his coefficients legitimately applicable to American mill-dams. This they certainly are not, and, while they may serve a useful purpose in measuring the flow of water in small modules, as in the partition of streams for irrigation purposes in the Western States, yet their chief interest to American engineers lies in the large number of facts which Bazin brought conspicuously before our attention, regarding the physical phenomena accompanying flow over weirs. The value of these results, qualitatively rather than quantitatively, can hardly be overestimated.

In this connection, one or two points may perhaps be brought out more strongly than has been done by Bazin in publishing his original researches. In order to show the effect of aprons of varying batter or slope, on the discharge coefficient, Bazin's Series, Nos. 136, 137, 141 and 142 have been selected. The experimental coefficients for each series have been plotted, and curves have been drawn, intended to fairly represent the experiments, as shown in Fig. 23. In each of these experiments the nappe appears to have adhered to the crest throughout all but the very lowest heads, for which there may have been a partial vacuum underneath the nappe, producing the short turn in the base of the first and second coefficient curves. In each case the

Mr. Horton.

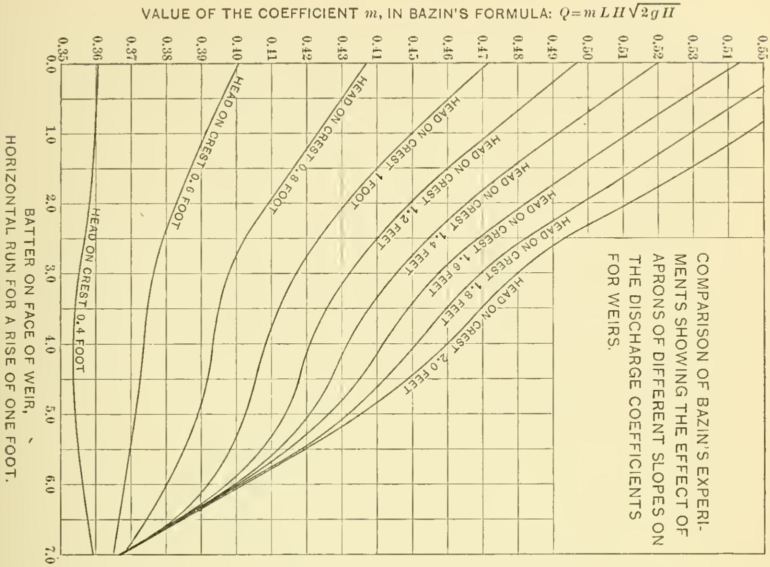


Fig. 24.

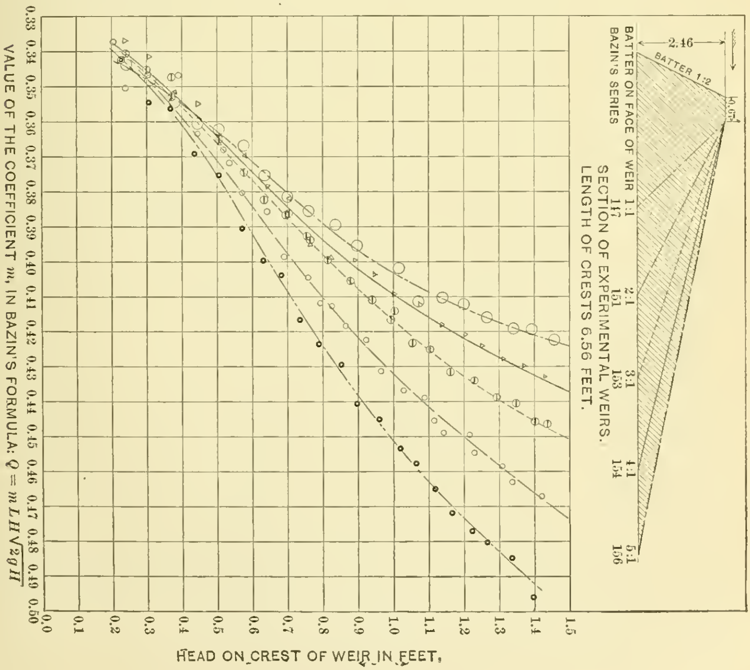


Fig. 25.

Mr. Horton. coefficients increased gradually with the head, indicating that the effect of the friction of the long flat apron diminished in proportion as the head increased. This illustrates a general statement which may be made that, as the head increases, the influence of peculiarities in the form of the weir section, in modifying the discharge coefficient, becomes less and less significant, and, under excessively high heads, the coefficient curves for all cross-sections will tend to converge.

A series of coefficients for various heads, taken from Fig. 23, has been plotted in a slightly different form in Fig. 22, using the coefficients as ordinates, and the slope or batter on the down-stream face as abscissas. This brings prominently to our notice the greatly diminished discharging capacity of a dam with a flat apron, as well as the tendency of all the curves to become tangent to a common asymptote under high heads.

Comparing, in the same manner as before, Bazin's Series Nos. 147, 151, 153, 154 and 156, we obtain the series of coefficient curves shown in Fig. 25. The cross-sections for these series are precisely like those shown in Figs. 22 and 23, except that, instead of having a vertical back, the up-stream face has a batter of 1 horizontal to 2 vertical, and a flat crest 0.67 ft. in width. The forms of the coefficient curves and the characteristics of discharge appear to be completely modified. Starting with nearly the same coefficients for all series at low heads, the coefficient curves diverge rapidly to the limit of the experiments. For low heads the influence of the apron is completely masked by the effect of the broad flat crest.

A number of similar comparisons might be made from Bazin's experiments, but enough has been given to show that no general formula for flow over a dam of irregular section, using the slopes of the faces and the breadth of the crest as independent variables, can be deduced; the coefficient curve for each combination must be determined separately, although the way in which any single element tends to modify the discharge may readily be pointed out.

In all the series of experiments above discussed, the nappe retained a sensibly stable form throughout the entire range of the experiment, being attached to the flat surface of the apron in each instance. The coefficient curves are continuous smooth lines. Where the nappe becomes depressed, detached or wetted underneath, during the progress of the experiment, the resulting coefficient curve, mathematically considered, will be a series of discontinuous arcs, possibly disconnected, and terminating abruptly in *points d'arret,* whenever the form of the nappe changes. Four series of coefficients, as deduced by Bazin, for weirs with variable nappes, are shown in Fig. 26. The condition of the nappe in each instance is indicated on the diagram. For dam sections like these the nappe may assume four distinct forms as regards

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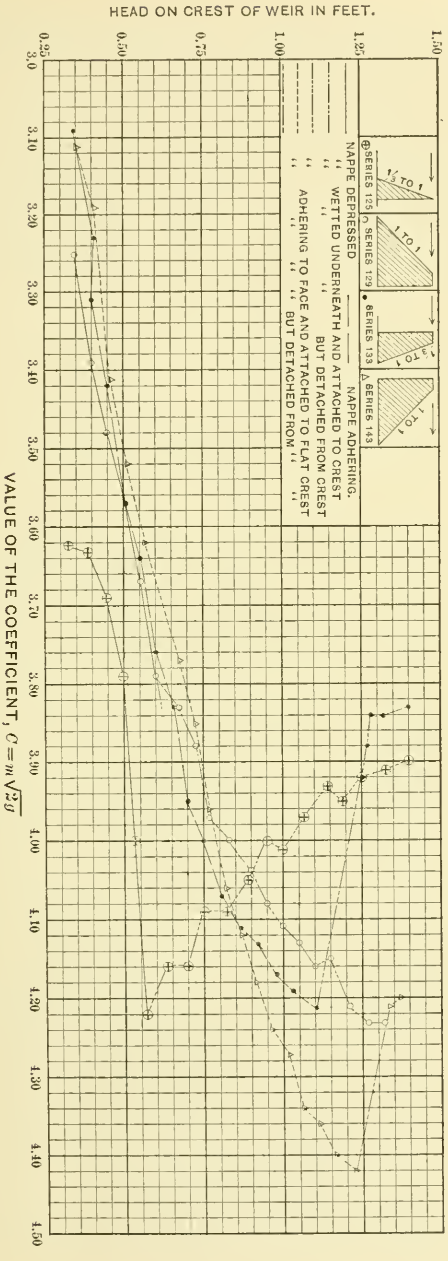

FIG. 26.

Mr. Horton. its behavior with reference to the down-stream face of the weir, and, in addition, it may either adhere to, or be detached from, the crest. Either of these conditions may occur in combination with any of the four previously mentioned, so that by simple permutation we find that eight series of discharge coefficients are possible for a single form of section. On the other hand, there are many forms of weirs, such, for example, as that used in Cornell experiment No. 19, for which the nappe adheres to the crest and apron under all heads, and is subject to no modifications whatever. Owing to the permanence of the nappe form, such a section possesses some advantages over a sharp-crested weir for use as a standard section in making weir measurements.

Mr. Parmley. WALTER C. PARMLEY, M. Am. Soc. C. E. (by letter.)—This paper is a welcome addition to the literature on weir flow. About all that has been known of this subject up to the present time is what has been given to us in the work of Francis, Fteley and Stearns, and Bazin. Their experiments cover a rather narrow range of conditions, and hence the experiments carried out at Cornell make a substantial addition to our knowledge of the subject.

In the method of measuring the head upon the weir, Mr. Rafter has followed in general the processes used by the other experimenters, although in details they are varied. The height above the crest of the weir is not taken by direct observation upon the water surface, but by observations of the water surface in glass gauges at the side of the channel. As a consequence, tedious and involved corrections must be applied to the readings obtained from one set of piezometers in order to make them check with the results of the others. This method introduces uncertainty as to the proper place in the channel of approach of placing the inlet tubing, the manner of access to it, and the possibility of eddies vitiating the results. It is doubtful if holes bored in round tubing will give a correct record of the head, inasmuch as the orifice is in a curved surface, when theory and experiment agree that the orifice should be at right angles to the motion of the water and through a plane surface parallel therewith. The experiments of Fteley and Stearns showed that the pressure near the up-stream side of the weir varied materially from the bottom to the top of the channel and with the distance from the weir. It is necessary, therefore, that the tubing enter the channel up-stream from this region of erratic pressures and, in a given case, it is not altogether certain just where these variations of pressure cease. The author does not explain whether or not any correction for capillary action in the piezometer tube was made, nor the amount, if such correction was made.

It seems to the writer that the method of Bazin is preferable. He provided recesses at the side of the channel where the actual surface of the water could be measured with a hook gauge. It undoubtedly

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has the advantage of avoiding the uncertainties mentioned. The author states that the readings of the piezometers were taken to 2 mm., that is, to within about 0.0066 ft. While an error of this amount is of no consequence when large heads are being measured, it becomes of considerable importance if the heads are small.

From his experience with many weirs under varying conditions, the writer has found the use of a steel tape graduated to hundredths of a foot very satisfactory. A sharp-pointed plumb-bob is attached to the end of the tape by means of a wire hook. The measurement to the surface of the water is taken from some well-defined point conveniently located above the water surface. These readings are made to thousandths, and in ordinary work can be made with certainty to within 0.005 ft., which is closer than the readings by the author's piezometers.

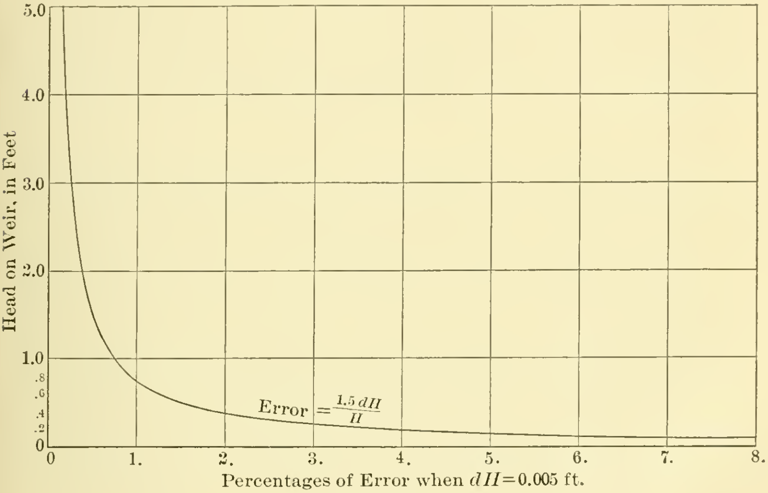

FIG. 27.

In order to illustrate the importance of accurate measurements when small heads are upon the weir and the relative unimportance of such accuracy for large heads, let us take the ordinary Francis formula, considering only a length of 1 ft. of weir.

$$Q = C\,H^{\frac{3}{2}}$$

Differentiate, and we have:

$$d\,Q = \tfrac{3}{2}\,C\,H^{\frac{1}{2}}\,d\,H$$

Now, the error of any gauging when $H + d\,H$ is taken as the head, Mr. Parmley. instead of the true head H, will be the quantity dQ, and the ratio of the error to the true quantity Q, will be,

$$\frac{d\,Q}{Q} = \frac{3\,C\,H^{\frac{1}{2}}\,d\,H}{2\,C\,H^{\frac{3}{2}}} = \frac{1.5\,d\,H}{H}$$

This formula gives the exact error if $d\,H$ is an infinitessimal, and a nearly correct value of the error if $d\,H$ is some very small quantity. Assuming $d\,H = 0.005$ ft. the writer has calculated the error for different heads upon the weir. The results are shown in Fig. 27, and are expressed as percentages of the true volume flowing. The heads are on the left and the corresponding errors for the various heads at the bottom of the diagram. It will be observed that if the head is 0.1 ft., the error is 7½%; if the head is 1 ft., the error is 0.75%, and if the head is 5 ft., the error is only 0.15 per cent. It seems to the writer, therefore, that the required degree of precision could have been attained, and with greater certainty as to the final results, if a simpler and more direct method of measuring the heads had been followed.

It is probable, also, that some of the irregularities in the resulting coefficients are due to the method of observing the head. There is no apparent reason why the coefficients of a standard sharp-crested weir should increase both ways from a minimum as shown in Fig. 7, and it is probable that the same cause accounts for the peculiarities in the coefficients of Experiments Nos. 1, 5, 12 and 16, whatever that cause may have been.

The writer, agreeing with Professor Williams, is unable to understand the author's use of Bazin's formula on page 296. After having correctly found the volume by the formula of Bazin, he apparently makes a further correction for velocity of approach, on pages 298 and 299. Even if such correction were necessary, the reason is not clear why the correction taken was $\frac{v^2}{2\,g}$, instead of $1.33\,\frac{v^2}{2\,g}$, given as the average value by Fteley and Stearns. If the writer understands Bazin's formula, no correction for velocity of approach is necessary, since that is taken account of already in the formula and the coefficients given in his table.

This suggests what seems to be an obscure point in the discussion of weirs in most text books on hydraulics. In order to use correctly any weir formula it is absolutely necessary to use it with the constants obtained by direct experiment for that formula; and it is also necessary that all the attending conditions should be the same as those under which the constants were determined. One, therefore, cannot correctly apply the Francis constants when reducing for velocity of approach by the method adopted by Fteley and Stearns, nor *vice versa*. In a similar manner, the Bazin constants are not directly applicable to

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the formulas obtained by Francis, and by Fteley and Stearns. If our text books had been more clear, there would have been less confusion regarding this point.

If the volume over a standard 16-ft. weir was not correctly obtained as above indicated, the subsequent work based upon these results would need correcting. It is to be hoped that the results as finally determined will be affected by no error which it is possible to eliminate.

Since, as a basis of the experiments performed at Cornell, the whole subject of weir flow is under discussion, it will probably be instructive to give a summary of the results of some of the deductions which the writer has made of the work of Francis, Fteley and Stearns, and Bazin.

As already stated, in order to obtain the most accurate results, it is necessary to duplicate the conditions of some weir for which coefficients have been determined by volumetric measurement, and then to use the same formula and the same coefficients derived from that weir. As a matter of fact, this is seldom possible in practice. The engineer is thus forced to resort to some modified method which, in his judgment, will give results most nearly correct under the circumstances.

The writer has constructed recently about forty weirs of various sorts, and not one of them conforms to any weir for which coefficients have been determined. Most of these weirs are in sewer outlets where the channel of approach is circular or nearly so. In all these weirs, with considerable head, the velocity of approach exceeds that of any upon which experiments have been conducted. While recognizing the desirability of constructing weirs without end contractions, in most cases it has been practically impossible, and where it could have been done, the cost precluded a weir of that form.

A close study, therefore, has been made of the work of these experimenters, in order, if possible, to discover a method which would utilize the results of all, when working with a weir unlike any which had been calibrated. One of the first things noticed was the fact that in correcting for velocity of approach, Bazin followed practically the method of Francis, but with a coefficient which gives a larger correction. There are two methods of making this correction: The theoretical method of Francis, in which the effective head, H', corrected for initial velocity of the water is

$$H' = \left[\left(H + \frac{v^2}{2\,g}\right)^{\frac{3}{2}} - \left(\frac{v^2}{2\,g}\right)^{\frac{3}{2}}\right]^{\frac{2}{3}}$$

and the empirical method used by Fteley and Stearns, in which the effective head is

$$H' = H + c\,\frac{v^2}{2\,g}$$

in which c is some numerical constant to be determined by experiment.

Mr. Parmley. Now, the correction for velocity of approach, to be applied to the coefficient for flow over a weir where there is no velocity of approach, adopted by Bazin, is

$$K = 1 + 0.55 \left(\frac{H}{H + P}\right)^2$$

which is identical in form with a formula, expressing the same thing, derived by Hunking and Hart:*

$$K = 1 + 0.2489 \left(\frac{H}{H + P}\right)^2$$

The value of K, by Bazin, differs only by the numerical coefficient, and gives a correction 2.2 times that of the formula of Hunking and Hart; but the values given by the latter equation were found to agree within one-two hundredth of 1% of the results obtained by the use of the Francis formula for effective head, given above. It thus appears that the correction for velocity of approach, as deduced by Bazin for use in the formulas for the weirs which he experimented with, is 2.2 times the correction that Francis found necessary to the formula in the reduction of his experiments.

The ratio $\frac{H}{H + P}$ was derived from rectangular channels and for suppressed weirs, and is, therefore, the ratio of the sectional area of the water upon the weir to the sectional area of the water in the channel of approach. Adopt the notation $\frac{a}{A}$ to represent this ratio and we may then apply the results of experiments upon suppressed weirs in rectangular channels, to weirs with end contractions in channels having any shape, provided the proper correction for end contraction be made. The formula of Francis, then, for suppressed weirs of such height that there is velocity of approach, becomes

$$Q = 3.33 \left[1 + 0.2489 \left(\frac{a}{A}\right)^2\right] L H^{\frac{3}{2}}$$

and Bazin's formula for the same case becomes

$$Q = C' \left[1 + 0.55 \left(\frac{a}{A}\right)^2\right] L H^{\frac{3}{2}}$$

in which C' = the coefficient where there is no velocity of approach.

In Bazin's formula, as thus modified, C' is not constant, as found to be nearly the case with the limited number of weirs experimented on by Francis, but varies from 3.59 for a head of 0.16 ft. to 3.28 for a head of 1.969 ft., and in the coefficient K, where the corrective term is 2.2 times that of Francis, as before stated.

Outside of the few experiments of Fteley and Stearns, the work of Francis is practically all that we have bearing on the subject of the

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* *Journal of the Franklin Institute*, Vol. 118 (Aug., 1884), p. 121.

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effect of end contraction. As it was found by Fteley and Stearns to vary from 0.06 to 0.12 of the head, and as their experiments are not extensive enough for us to determine in most cases just what correction to make, the average correction of Francis seems to be the most practicable value to use, viz., 0.10 of the head deducted from the length of the weir for each end contraction. A general formula for sharp-crested weirs, either suppressed or contracted, may then be written

$$Q = C' \, K \, [L - 0.1 \, n \, H] \, H^{\frac{3}{2}}$$

in which n is the number of end contractions and K is the coefficient obtained by Bazin, since his experiments cover so large a number of conditions.

The values of C', as deduced by Bazin, do not fit exactly the work of American experimenters, and an investigation of this point has been made. The values of C', as deduced from the experiments of Francis, and Fteley and Stearns, after the correction for end contraction and velocity of approach had been made, are plotted in Fig. 28. The values of Bazin, for the case of no end contraction and no velocity of approach, are also plotted. In this manner the variations in the results of the experiments are set clearly before the eye. By the curve it is seen that the values of Bazin agree well with each other, but that he uniformly gives higher values than do either of the other experimenters. In order to write a formula capable of covering, with a fair degree of accuracy, a wide range of conditions and still give proper weight to the results of all three authorities, values of C' are taken from the curve which is drawn in an intermediate position.

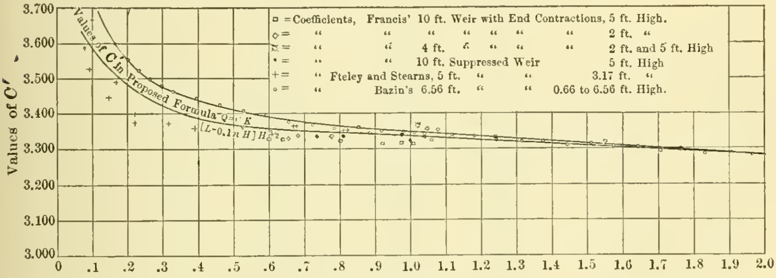

FIG. 28.

Values of K for variations in the ratio $\frac{a}{A}$ from 0.01 to 0.60 are shown in Table No. 11, together with the values of C' taken from the intermediate curve of Fig. 28.

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TABLE No. 11.—VALUES OF THE COEFFICIENTS IN THE FORMULA

$$Q = C' \ K \ (L - 0.1 \ n \ H) H^{\frac{3}{2}}$$

a = $(L - 0.1 \ n \ H) \ H$;

A = Area of water section in channel of approach;

$\frac{a}{A}$ = Ratio of area of weir section to area of section of channel of approach;

K = Constant for given value of $\frac{a}{A}$;

C' = Constant for given value of H.

$\frac{a}{A}$	K.	$\frac{a}{A}$	K.	H.	C'.
0.01	1.0001	0.31	1.0529	0.10	3.580
0.02	1.0002	0.32	1.0563	0.15	3.520
0.03	1.0005	0.33	1.0599	0.20	3.478
0.04	1.0009	0.34	1.0636	0.25	3.444
0.05	1.0014	0.35	1.0674	0.30	2.420
0.06	1.0020	0.36	1.0713	0.35	3.400
0.07	1.0027	0.37	1.0753	0.40	3.385
0.08	1.0035	0.38	1.0794	0.45	3.376
0.09	1.0044	0.39	1.0837	0.50	3.368
0.10	1.0055	0.40	1.0880	0.55	3.362
0.11	1.0066	0.41	1.0925	0.60	3.358
0.12	1.0079	0.42	1.0970	0.65	3.354
0.13	1.0093	0.43	1.1017	0.70	3.351
0.14	1.0108	0.44	1.1065	0.75	3.349
0.15	1.0124	0.45	1.1114	0.80	3.346
0.16	1.0141	0.46	1.1164	0.85	3.343
0.17	1.0159	0.47	1.1215	0.90	3.340
0.18	1.0178	0.48	1.1267	0.95	3.337
0.19	1.0198	0.49	1.1321	1.00	3.334
0.20	1.0220	0.50	1.1375	1.10	3.329
0.21	1.0243	0.51	1.1431	1.20	3.324
0.22	1.0266	0.52	1.1487	1.30	3.319
0.23	1.0291	0.53	1.1545	1.40	3.313
0.24	1.0317	0.54	1.1604	1.50	3.307
0.25	1.0344	0.55	1.1664	1.60	3.301
0.26	1.0372	0.56	1.1725	1.70	3.296
0.27	1.0401	0.57	1.1787	1.80	3.290
0.28	1.0431	0.58	1.1850	1.90	3.285
0.29	1.0463	0.59	1.1915	2.00	3.280
0.30	1.0495	0.60	1.1980	....	.....

The formula, then, with the aid of the auxiliary table for C' and K, is capable of application to sharp-crested weirs, with or without end contractions, with any form of channel of approach and with a great range in the velocity of approach, these corrections being applied separately, and provided for by the coefficients in the general formula.

In order to make a direct comparison of the two methods of reducing for velocity of approach, we may consider any given quantity of flow to be calculated by the two formulas. By equating these expres-

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sions for volume we can obtain values of the coefficients that will satisfy the equation. Then let

$$Q = C' K L H^{\frac{3}{2}} = C' L (H + ch)^{\frac{3}{2}}$$

from which

$$K^{\frac{2}{3}} H = (H + ch)$$

or,

$$c = \frac{H}{h} (K^{\frac{2}{3}} - 1).$$

But

$$h = 0.01555\ v^2 = 0.01555\ \frac{Q^2}{A^2} = \frac{0.01555\ (C')^2\ K^2\ L^2\ H^3}{A^2}$$

$$= 0.01555\ (C')^2\ K^2\ H \frac{a^2}{A^2}$$

From the equation for K, given above, we have

$$A^2 = \frac{0.55\ a^2}{K - 1}$$

Substituting this value of A^2 in the equation for h, and then substituting the value of h in the equation for c and reducing gives

$$c = \frac{35.4\ (K^{\frac{2}{3}} - 1)}{(C')^2\ K^2\ (K - 1)}$$

Since, in the second member of the last equation, there are two variables, C' and K, which are given for any depth of weir and any head upon the weir, the equation enables us to determine, after having found the volume by the equation $Q = C'\ K\ L\ H^{\frac{3}{2}}$, precisely what value of c would have been necessary to use in the formula $Q = C'\ L\ (H + ch)^{\frac{3}{2}}$ in order to obtain the same volume.

Fig. 29 shows the value of c for several weirs and heads as given by Fteley and Stearns* and the values for the same volumes flowing when calculated by the formula $Q = C'\ K\ L\ H^{\frac{3}{2}}$. The values by Fteley and Stearns are shown by broken lines, and those by the latter formula by solid lines.

It will be seen that the values of c by the two methods for a weir 1 ft. high are almost identical, but that for higher weirs, with consequently lower velocities of approach, the values by Fteley and Stearns are lower. On the other hand, by the Bazin formula with modified coefficients, the values of c increase as the weirs become higher and the velocities of approach become less. It would seem that the latter condition is the more reasonable since there appears to be more pressure head

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* *Transactions*, Am. Soc. C. E., Jan., 1883, Table III, p. 22.

Mr. Parmley. proportionately with low velocities immediately behind the weir than with greater initial velocities. It also seems to accord with other observations of Fteley and Stearns which showed that the value of c is greater for weirs with end contraction than for suppressed weirs.

Whether or not this be true, the values by the latter formula show a regular law of variation, since c increases in every instance with an increase in the height of the weir, while the values as given by Fteley and Stearns for a weir 1.7 ft. high are intermediate between those for weirs 1 ft. and 0.5 ft. high; and for a weir 2.6 ft. high they are less than those for any of the others. Such results are anomalous, and seem to show that the values derived by their experiments were affected by some peculiar condition which may not occur in other cases. In Table No. 12 a direct comparison of the values of c is shown for the cases having one or more end contractions, as given by Fteley and Stearns.* The values of c are calculated by the formula for c, given above. From this, together with the data in the table of Fteley and Stearns, a comparison of the velocity heads is made, with the difference between them shown in the last column.

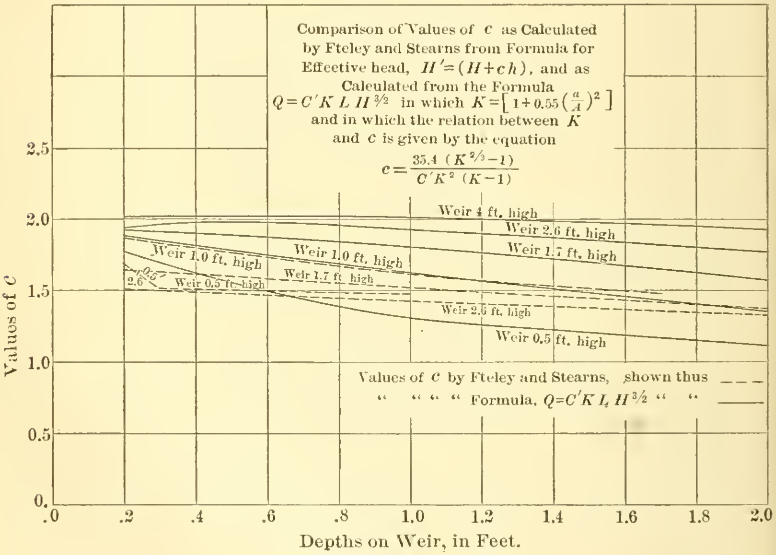

FIG. 29.

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* *Transactions*, Am. Soc. C. E., Vol. xii, Table No. III, pp. 22 and 23.

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TABLE No. 12.—COMPARATIVE VALUES OF c IN THE FORMULA FOR EFFECT OF VELOCITY OF APPROACH $H' = (H + c\,h)$ AS GIVEN BY FTELEY AND STEARNS, AND AS GIVEN BY THE FORMULA $c = \frac{35.4\,(K^{\frac{3}{2}} - 1)}{(C')^2\,K^2\,(K - 1)}$.

The calculations are based on the weirs shown in *Transactions*, Am. Soc. C. E., Vol. xii, Table No. III, pp. 22 and 23.

No. of experiment. (1)	Height of weir. (2)	Length of weir. (3)	Number of end contractions. (4)	Measured head on weir. (5)	Value of c given by Fteley and Stearns. (6)	Value of c given by formula. (7)	Value of ch given by Fteley and Stearns. (8)	Value of h by Fteley and Stearns. (9)	Value of h by formula for c. (10)	Column (10) deducted from column (9). (11)
1	3.56	3.0	2	0.8702	*2.14	2.08	0.0042	0.0020	0.0020	0.0000
2	1.70	3.0	2	0.8612	2.26	2.03	0.0132	0.0058	0.0065	— 0.0007
3	1.00	3.0	2	0.8490	2.27	1.95	0.0254	0.0112	0.0130	— 0.0018
4	0.50	3.0	2	0.8310	2.00	1.83	0.0434	0.0217	0.0237	— 0.0020
5	3.56	3.3	1	0.5765	*2.02	2.08	0.0017	0.0008	0.0008	0.0000
6	1.00	3.3	1	0.5647	2.35	1.96	0.0135	0.0057	0.0069	— 0.0012
7	0.50	3.3	1	0.5574	1.65	1.83	0.0208	0.0126	0.0114	+ 0.0012
8	3.56	3.3	1	0.8062	*2.00	2.03	0.0040	0.0020	0.0020	0.0000
9	2.60	3.3	1	0.8036	1.99	2.05	0.0066	0.0033	0.0032	+ 0.0001
10	1.70	3.3	1	0.7969	2.16	2.01	0.0133	0.0062	0.0066	— 0.0004
11	1.00	3.3	1	0.7850	2.09	1.92	0.0252	0.0121	0.0131	— 0.0010
12	0.50	3.3	1	0.7677	1.78	1.77	0.0425	0.0239	0.0240	— 0.0001
13	3.56	3.3	1	0.9307	*1.99	2.09	0.0058	0.0029	0.0028	+ 0.0001
14	1.00	3.3	1	0.9024	2.10	1.90	0.0341	0.0162	0.0179	— 0.0017
15	0.50	3.3	1	0.8775	1.91	1.75	0.0590	0.0309	0.0337	— 0.0028
16	3.56	4.0	1	0.7048	*1.81	2.05	0.0038	0.0021	0.0019	+ 0.0002
17	0.50	4.0	1	0.6639	1.58	1.67	0.0447	0.0283	0.0268	+ 0.0015

* Value used to determine effective depth on weir, and not the result of experiment.

By the last column of differences it will be observed that the values as calculated are within the limits of error in making the observation of the head upon the weir, and this fact, together with the probability that some small errors in readings were made by Fteley and Stearns, seems to make the calculated value of c practically exact in any given case.

To test the preceding work still further, and if possible remove any doubt there may be in its reliability, the volumes of discharge have been calculated for the various experiments made by Francis, and Fteley and Stearns, so that these calculated volumes could be compared with the volumes obtained by them from direct volumetric measurement. These results, together with the percentage of variation of calculated from measured volumes, are shown in Tables Nos. 13 to 17.

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TABLE No. 13.—Experiments by Francis.

Case I.—Length of weir, 9.997 ft.; width of channel above weir, 13.96 ft.; mean depth of channel below crest of weir, 6 ft., above weir, 5.048 ft.

No. of Francis' Experiments (Mean of Nos.).	Measured head.	Actual Q, in cubic feet.	Q' by formula, in cubic feet.	$\frac{Q'}{Q}$
72, 73, 74	0.5983	15.2466	15.397	1.010
76, 77, 78	0.63823	16.7777	16.942	1.010
75	0.65525	17.4305	17.612	1.010
56, 57, 58, 59, 60, 61	0.79899	23.4304	23.66	1.009
22, 23	0.9218	28.9334	29.20	1.009
11, 17, 18, 19, 24, 31, 32, 33	0.9701	31.2479	31.466	1.007
12, 20, 21, 25, 26, 27	1.0050	32.9542	33.16	1.006
13, 14, 15, 16, 28, 29	1.0390	34.5975	34.823	1.007
30	1.0692	36.1752	36.313	1.004
5, 6, 7, 8, 9, 10	1.2476	45.5654	45.60	1.001
1, 2, 3, 4	1.5508	62.602	62.60	1.000

Case II.—Same conditions as in Case I, except that weir was divided into two bays by a central partition 2 ft. wide. Each resulting weir, 3.999 ft. long.

34, 35	1.0182	13.138	13.06	0.994

Case III.—Weir 9.997 ft. long; complete end contraction; depth of channel below crest of weir, 2.014 ft; width of channel, 13.96 ft.

79, 80, 81, 82, 83, 84	0.6493	17.3400	17.60	1.015
62, 63, 64	0.7876	23.2658	23.518	1.011
65, 66	0.8841	27.7038	27.704	1.010
36, 37, 38, 39, 40, 41	1.0420	35.5792	35.820	1.007
42, 43	1.0753	37.2693	37.55	1.007

Case IV.—Same conditions as in Case III, except that the weir was divided into two bays by a central partition 2 ft. wide, thus making two weirs each 3.999 ft. long.

85, 86, 87, 88	0.6800	7.2739	7.352	1.011

Case V.—Suppressed weir, 9.995 ft. long; width of channel, 9.992 ft.; depth below crest of weir, 5.048 ft.

67	0.7362	21.1532	21.33	1.009
68, 69, 70, 71	0.8099	24.4498	24.629	1.007
44, 45, 46, 47, 48, 49, 50	0.9790	32.5616	32.751	1.006
51, 52, 53, 54, 55	1.00026	33.4946	33.50	1.010

TABLE No. 14.—Experiments by Fteley and Stearns.

Mr. Parmley.

Sharp-crested weir with end contractions suppressed; weir 3.17 ft. high above bottom of channel; rectangular channel of approach.

No. of Experiment.	Length of weir.	Measured head.	Actual Q, in cubic feet.	Q' by formula, in cubic feet.	$\frac{Q'}{Q}$
1	5.000	0.8198	12.750	12.66	0.9944
3	5.000	0.8118	12.466	12.519	1.004
4	5.000	0.6761	9.430	9.473	1.005
5	4.997	0.6713	9.322	9.379	1.006
6	4.996	0.5203	9.342	6.385	1.007
8	4.999	0.4761	5.547	5.590	1.008
9	4.999	0.4569	5.199	5.257	1.011
10	4.999	0.3890	4.094	4.138	1.011
12	4.994	0.3407	3.3540	3.402	1.014
13	4.998	0.3114	2.9355	2.980	1.015
14	4.999	0.2598	2.2415	2.284	1.019
15	4.999	0.2467	2.0780	2.115	1.018
17	5.000	0.2190	1.7474	1.779	1.018
18	5.000	0.2182	1.7211	1.769	1.028
19	5.000	0.2176	1.7837	1.762	0.988
20	4.998	0.1650	1.1705	1.177	1.005
21	4.995	0.1627	1.1367	1.153	1.014
22	4.995	0.1444	0.9469	0.9681	1.022
23	4.998	0.1235	0.7495	0.7452	0.994
24	4.998	0.1225	0.7526	0.7623	1.013
27	4.996	0.1009	0.5846	0.5731	0.978
28	4.996	0.1008	0.5877		
29	4.996	0.0991	0.5498	0.5582	1.015
31	4.996	0.0746	0.3652	0.3648	0.999

TABLE No. 15.

Sharp-crested weir with end contractions suppressed; weir 18.996 ft. long and 6.55 ft. high above bottom of channel.

Number of Experiment.	Measured head.	Actual Q, in cubic feet.	Q' by formula, in cubic feet.	$\frac{Q'}{Q}$
1	1.6038	130.117	130.341	1.002
2	1.4546	112.066	112.313	1.002
3	1.2981	94.192	94.652	1.005
5	1.1456	77.783	78.415	1.008
6	0.9873	62.061	62.713	1.011
7	0.9864	62.023	62.609	1.010
8	0.8191	46.760	47.491	1.016
9	0.6460	32.685	33.226	1.017
10	0.4685	20.178	20.596	1.021

TABLE No. 16.

Experiments on weirs in channel 5 ft. wide, and with height of weirs 3.56 ft. above bottom of channel; dimensions of weirs as shown in the table:

Number designating form of weir.	Number of end contractions.	Length of weir.	Distance from side of channel to the end of weir.	
			North side.	South side.
1	0	5.0	0.0	0.0
2	1	4.0	1.0	0.0
3	1	4.0	0.0	1.0
4	1	3.3	0.0	1.7
5	2	3.0	1.0	1.0
6	2	2.3	1.0	1.7

Mr. Parmley.

TABLE No. 17.

Number of Experiment.	Number designating form of weir by Table No. 16.	Measured head, in feet.	Actual Q, in cubic feet.	Q' by Formula, in cubic feet.	$\frac{Q'}{Q}$
1	1	0.1509	1.007	1.034	1.026
4	5	0.2155	1.007	1.028	1.021
6	2	0.2303	1.868	1.917	1.026
7	2	0.2691	1.868	1.911	1.023
8	3	0.2693	1.869	1.913	1.024
9	5	0.3301	1.869	1.905	1.019
10	1	0.2304	1.869	1.918	1.026
11	1	0.3368	3.283	3.343	1.018
12	2	0.3942	3.283	3.336	1.016
13	3	0.3944	3.283	3.340	1.017
14	5	0.4843	3.284	3.317	1.010
15	4	0.4498	3.284	3.337	1.016
16	6	0.5824	3.284	3.287	1.001
17	1	0.3369	3.285	3.380	1.019
18	1	0.4244	4.636	4.707	1.015
19	3	0.4978	4.636	4.705	1.015
20	4	0.5678	4.637	4.697	1.013
21	1	0.4245	4.637	4.719	1.015
22	1	0.4308	4.741	4.813	1.015
23	5	0.6215	4.736	4.761	1.005
24	6	0.7478	4.736	4.701	0.992
25	4	0.5764	4.736	4.805	1.015
26	4	0.5766	4.736	4.807	1.015
27	1	0.4302	4.731	4.814	1.015
28	1	0.5115	6.132	6.217	1.014
29	2	0.5997	6.134	6.197	1.010
30	3	0.5996	6.134	6.196	1.010
31	5	0.7398	6.134	6.130	1.000
32	4	0.6860	6.134	6.212	1.013
33	6	0.8905	6.134	6.019	0.981
34	1	0.5117	6.136	6.221	1.014
35	6	0.9548	6.796	6.640	0.977
36	1	0.5477	6.796	6.907	1.016
37	1	0.6010	7.814	7.918	1.013
38	2	0.7055	7.815	7.892	1.010
39	3	0.7064	7.815	7.905	1.011
40	5	0.8714	7.815	7.769	0.994
41	1	0.6011	7.816	7.920	1.013
42	4	0.8062	7.815	7.889	1.009
43	4	0.8063	7.804	7.886	1.010
44	1	0.6002	7.798	7.902	1.013
45	5	0.8702	7.800	7.752	0.994
Mean of 46, 47	1	0.69245	9.677	9.805	1.013
48	4	0.9317	9.667	9.755	1.009
49	4	0.9297	9.630	9.724	1.010
50	1	0.6897	9.618	9.743	1.013
51	2	0.9448	12.147	12.174	1.002
52	3	0.9432	12.147	12.137	1.001
53	1	0.8047	12.147	12.311	1.013
54	2	0.9460	12.147	12.205	1.004

It is thus seen that the formula, when applied to the experiments of Francis, and of Fteley and Stearns, agrees within about 1%, usually, even through a very wide range of conditions. For the most part, the formula gives results too large for these experiments. If applied to the work of Bazin, on the other hand, the results for small heads will be found to be too small by about the same percentage, and for larger heads the error approaches zero. The formula, with the coefficients as they stand, gives about equal weight to the work of all these

Mr. Parmley.

experimenters, and may therefore be used with a good deal of confidence in cases where the conditions are not exactly like those of weirs actually tested. In general, it will be noticed that the percentage of variation is greater for small depths than for large depths on the weir. As, for small heads, the experimental errors are also proportionately greater, the errors of the formula are of less consequence than they would be if they increased with the depth on the weir.

A serious difficulty with the method of calculating the effective head by the formula $H' = H + c\,h$ is the fact that the value of c varies, not only with the varying head, but with every depth of weir, and, as Fteley and Stearns found, with the condition as to end contraction. This difficulty is in part obviated by the foregoing process.

To the writer's mind, the conclusion to be drawn from the foregoing discussion is that the methods adopted by Francis and by Bazin when investigating the effect of velocity of approach are preferable to the method used by Fteley and Stearns. This conclusion seems to be confirmed by the fact that it is possible to write a single formula, with a supplemental table of values of C', depending on the head upon the weir, and a table of values of K, depending on the relative areas of water section on the weir and in the channel of approach, which will give results nearly approximating the true quantities of discharge for a very wide range of conditions.

It is to be hoped that the experiments, so well begun at Cornell University, may be continued until the subject of weir flow is taken out of the cloud of uncertainty in which at present it is enveloped.

Mr. Nelles.

George T. Nelles, M. Am. Soc. C. E. (by letter).—Only those engineers, whose practice has shown them the difficulties and uncertainties involved in the determination of the flow of water over dams of practical form and dimensions, will ever fully realize the great service rendered to the profession by the experiments of Bazin and those made for the U. S. Board of Engineers on Deep Waterways by the author, at the Cornell Hydraulic Laboratory.

The Cornell experiments are presented in a practical and useful form and admit of an easy and direct application to the solution of questions concerning the flow of water over dams, met with in everyday practice by the working engineer.

Early in the course of a recent investigation to determine the probable effect of the construction of several large dams in the Tennessee River, for the purpose of producing slack-water navigation, the writer recognized the inapplicability of the existing published data, based on small-scale experiments, and made a systematic effort to secure information of a more practical nature, founded on actual observations on the flow over existing dams. His efforts in this direction, which comprised a study of the available literature on the subject, and correspondence with many of the most eminent hydraulic

Mr. Nelles. engineers of this country and Europe, met with small success, and exhibited the paucity of exact knowledge of this nature.

The best results obtained, relating to the free discharge into air, were as follows:

(1) From Dwight Porter, M. Am. Soc. C. E., five observations, made in 1894 by two students of the Massachusetts Institute of Technology, on the flow over a dam in the Blackstone River, at Albion, Mass. The dam is 217 ft. long, with a longitudinal timber crest 12 ins. wide; the lower face is vertical, and the upper face is covered with rip-rap stone, sloping at about 30° with the horizontal; the height of the dam is about 8 ft. The discharge was measured by meter at a section 500 ft. below the dam. The head was measured by a hook gauge, located 20 ft. above the crest of the dam.

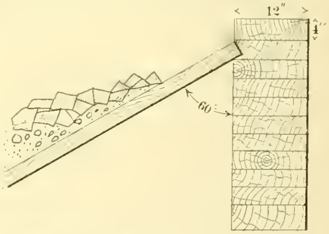
These observations when applied to the Bazin formula

$$Q = m\,L\,h\,\sqrt{2\,g\,h} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (a).$$

in which m represents the coefficient of discharge, L the crest length of the dam and h the observed head, give the values for the coefficient m shown in Table No. 18.

TABLE No. 18.

Observation.	Observed head, in feet.	Coefficient m.
(1)............	0.735	0.439
(2)............	0.867	0.441
(3)............	0.829	0.456
(4)............	0.973	0.491
(5)............	1.025	0.470



Concerning these results, Professor Porter says: "The coefficients are sufficiently high and discordant to be unsafe for acceptance unless otherwise confirmed."

(2) From W. H. Bixby, M. Am. Soc. C. E., Major, Corps of Engineers, U. S. A., four observations on the flow over dams in the Muskingum River, Ohio. The discharge was obtained by carefully sounding the area of a section 500 ft. above each dam, and measuring the velocity by long rod floats. The mean velocity was deduced from the observed, by the formula given in Johnson's "Surveying."

The dams are constructed of timber cribs, filled with stone, and have planked sloping crests. The upper face is 10 ft. long, with a slope of 1 ft. The lower face is 30 ft. long, with a slope of 4 ft.*

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* *The Engineering Record*, March 8th, 1890, page 216.

Table No. 19 gives the results of these observations. Mr. Nelles.

TABLE No. 19.

Number of dam.	Length on crest, in feet.	Mean height, in feet.	Area of discharge section, in square feet.	Discharge, in cubic feet per second.	Mean velocity, in feet per second.	Fall over dam, in feet.	Observed depth on crest, in feet.	Coefficient, in the Bazin formula (m).
3..............	848	12.6	7 765	18 118	2.333	8.00	2.86	0.551
4..............	535	15.9	8 360	25 559	3.045	6.70	4.66	0.589
7..............	472	14.2	8 230	21 015	2.553	7.00	4.40	0.600
8..............	515	16.0	7 330	22 310	3.044	5.16	5.90	0.376

T. C. Clarke, M. Am. Soc. C. E., gives certain results* concerning the flow over a dam in the Ottawa River, from which the following is abstracted. The dam is 30 ft. high, built of stone-filled timber cribs, with upper and lower faces planked and sloping at 3 horizontal to 1 vertical. The data are shown in Table No. 20.

TABLE No. 20.

Length, in feet.	Depth on crest, in feet.	Discharge, in cubic feet per second.	Coefficient m in the Bazin formula.
1 600	2.5	26 000	0.512
1 760	10.0	190 000	0.425

In a paper read before the American Society of Mechanical Engineers in 1897, Professor R. C. Carpenter, of Cornell University, gave the results of a number of observations made by him at the Bridgeport Pumping Station, Chicago, on the flow over a vertical weir, 30 ft. long and 8.7 ft. high, with a sharp crest.

The discharge was measured by carefully conducted rod float observations, and checked by the known capacity of the basin. After correcting for two end contractions, Professor Carpenter gives the figures shown in Table No. 21.

TABLE No. 21.

Observed heads, in feet, corrected for velocity of approach..................................	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Coefficient c in Francis' formula............	3.657	3.609	3.577	3.560	3.545	3.537	3.529

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* *Transactions*, Am. Soc. C. E., Vol. xxxiv, page 508.

Mr. Nelles.

The coefficients given by the Massachusetts Institute of Technology observations and the Muskingum River observations have been plotted on the diagram, Fig. 30, in comparison with Bazin's Series No. 178; and appear to justify the early conclusions drawn from the Bazin experiments, that for weirs with sloping faces, the coefficients increase with the head. When, however, we compare these coefficients with the Cornell experiments, of which Series No. 8 is taken as a type, and shown in Fig. 30, we are met by complications which give rise to just doubts as to the accuracy of the observations in question, or the applicability of experiments, even on the large scale of those carried out at Cornell, to the flow over structures differing in shape and dimensions from the experimental forms. While both causes may combine to produce the apparent discrepancies, the former is doubtless the leading factor.

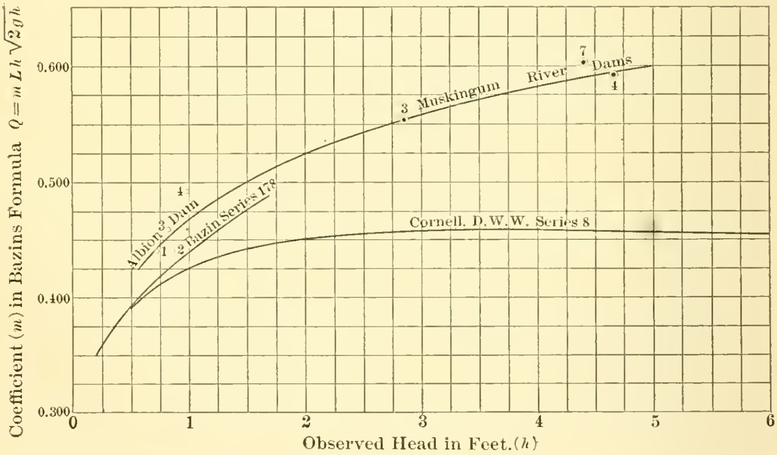

Fig. 30.

The practical solution of most questions concerning the free flow over weirs and dams of the usual forms is rendered comparatively easy and simple by the experiments recorded in this paper. The solution of questions concerning the flow over submerged or drowned weirs is still, however, involved in doubt and uncertainty, although the recent experiments by Bazin, covering this form of flow, have added greatly to our knowledge, and afford a basis for a comprehensive study, which will doubtless eventually lead to a better, if not a complete, understanding of the governing principles. A knowledge of this form of flow, which is of relatively less importance to engineers in general than a knowledge of free flow, is nevertheless essential in the study of various engineering problems.

Mr. Nelles.

The experiments of Francis, Fteley and Stearns, Bazin, and others, have determined, within the limits of their experiments, the law of variation of the coefficient of discharge for submerged flow over sharp-crested vertical weirs. The results of and the deductions from the experiments of Francis, and Fteley and Stearns, are to be found in the *Transactions* of this Society,* to all of which reference is made. Bazin has applied the results of his experiments on submerged flow over weirs with sharp crests, in thin partition, to the same formula he used for free discharge into air,

$$Q = m\,L\,h\,\sqrt{2\,g\,h} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (a)$$

and has deduced the two expressions (Equations 11 and 12, page 270), for the coefficient of discharge m. In these equations (11 and 12) m' represents the coefficient of free discharge for a similar weir of the same height, with the same depth h of water in the pool above the weir on the crest. The depth of the water in the pool below the weir on the crest is represented by h_1; p represents the height of the weir, and $z = h - h_1 =$ the difference in level of the water surface above and below the weir. These expressions, in connection with the well-determined coefficients of free discharge given in Table No. 2 afford an easy and safe means of obtaining the coefficient for submerged flow for the conditions and limits comprised in Bazin's experiments, Series Nos. 64 to 85, 4th article, 1894.

In his 5th article, 1896, Bazin treats of the submerged flow over vertical weirs with flat crests (*deversoirs à poutrelles*), made up of square timbers of the same width as the crest. Concerning these experiments he says:

> "Independent of the experiments we have just studied (experiments on the free flow over similar weirs), there have been made, by raising the level of the water surface below the weirs, four other series, on weirs 0.75 m. (2.46 ft.) and 0.35 m. (1.15 ft.) high above the bed of the channel, with crests 0.20 m. (0.66 ft.) and 0.10 m. (0.33 ft.) wide.
>
> "They are entirely analogous to those which were made on vertical weirs in thin partition† (Series 64 to 85), and exactly the same methods have been followed in measuring the discharge, pressure, etc.
>
> "The discharge was regulated to correspond to constant heads of 0.10 m., 0.15 m. * * * * 0.40 m., 0.45 m. (0.325 ft., 0.492 ft. * * * * 1.148 ft., 1.312 ft.), on the standard weir of comparison. When the discharge corresponding to a given head became constant, then the level of the water surface below the weir was successively changed to 0.04p, 0.08p, 0.12p, etc. ($p =$ height of weir), both above and below the crest, as was done in the similar experiments on weirs in thin partition. Finally, a similar series was executed on a vertical weir 2.0 m. (6.56 ft.) wide."

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* *Transactions*, Am. Soc. C. E., Volumes xii, xiii and xiv.

† In his articles Bazin refers to weirs similar in form to his standard weir, as weirs in thin partition (*Déversoirs en mince paroi*). These weirs are made up of horizontal timbers about 4 ins. square, the crest being formed by an iron plate ¼ in. thick, in the prolongation of the back of the weir and extending 4 ins. above the timbers.

Weirs of other form, with sharp crest, Series 195, 196 and 197, he designates as weirs with sharp crest (*Déversoirs à vive arête*).

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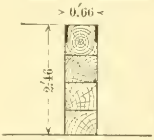
Bazin's Experiments.—Series Nos. 120 to 123.

Nappe wetted underneath, with water retained in pool below weir. Description of weirs under observation: Height, 0.75 m. = 2.46 ft. and 0.35 m. = 1.15 ft. Crests, 0.20 m. = 0.66 ft. and 0.10 m. = 0.33 ft. wide. Length, 2.0 m. = 6.56 ft.

Dimensions of standard weir used for measuring the discharge: Height, 1.135 m. = 3.72 ft. Length, 2.0 m. = 6.56 ft.

(1)	(2)	(3)	(4)	(5)
	Observed Heads, in Feet.		Height of the retained water with reference to crest: + = above, − = below. (h.)	Coefficients of Discharge.
	On weir under consideration. (h.)	On standard weir of comparison. (H.)		For the Bazin Formula ($Q = m L h \sqrt{2 g h}$)
	Bazin's Series No. 120.			
1	0.388	0.329	−0.199	0.3379
2	0.394	0.335	−0.097	0.3391
3	0.395	0.336	−0.002	0.3388
4	0.392	0.332	+0.191	0.3373
5	0.402	0.331	+0.294	0.3241
6	0.447	0.331	+0.392	0.2758
7	0.539	0.333	+0.494	0.2100
1	0.548	0.496	−0.392	0.3684
2	0.550	0.496	−0.200	0.3671
3	0.549	0.489	+0.000	0.3602
4	0.558	0.498	+0.098	0.3605
5	0.552	0.484	+0.187	0.3525
6	0.569	0.498	+0.296	0.3502
7	0.569	0.486	+0.392	0.3378
8	0.605	0.498	+0.490	0.3194
9	0.680	0.492	+0.589	0.2629
10	0.760	0.498	+0.686	0.2269
1	0.699	0.657	−0.394	0.3878
2	0.701	0.657	−0.197	0.3858
3	0.710	0.660	−0.001	0.3810
4	0.717	0.662	+0.199	0.3774
5	0.723	0.664	+0.290	0.3737
6	0.723	0.664	+0.295	0.3740
7	0.722	0.655	+0.388	0.3683
8	0.742	0.663	+0.492	0.3589
9	0.765	0.654	+0.593	0.3369
10	0.837	0.660	+0.687	0.2980
11	0.909	0.658	+0.783	0.2621
1	0.842	0.826	−0.589	0.4126
2	0.841	0.818	−0.395	0.4077
3	0.846	0.823	−0.198	0.4081
4	0.852	0.825	−0.004	0.4053
5	0.854	0.824	+0.104	0.4034
6	0.861	0.829	+0.189	0.4021
7	0.862	0.828	+0.193	0.4009
8	0.867	0.830	+0.290	0.3981
9	0.861	0.819	+0.291	0.3952
10	0.861	0.812	+0.419	0.3905
11	0.890	0.820	+0.587	0.3762
12	1.006	0.829	+0.786	0.3184
13	1.131	0.819	+0.980	0.2621
1	0.979	0.998	−0.288	0.4386
2	0.974	0.983	−0.396	0.4318
3	0.987	0.995	−0.199	0.4316
4	0.984	0.985	0.000	0.4266
5	0.990	0.982	+0.197	0.4207
6	1.000	0.989	+0.294	0.4191
7	1.003	0.982	+0.392	0.4130
8	1.005	0.988	+0.393	0.4151
9	1.006	0.979	+0.491	0.4088
10	1.014	0.991	+0.492	0.4112
11	1.020	0.984	+0.588	0.4034
12	1.024	0.987	+0.595	0.4034
13	1.046	0.988	+0.658	0.3917
14	1.102	0.987	+0.788	0.3617
15	1.158	0.988	+0.887	0.3318
16	1.226	0.994	+0.980	0.3111
17	1.288	0.988	+1.082	0.2862
18	1.358	0.992	+1.182	0.2657
1	1.111	1.157	−0.584	0.4541
2	1.117	1.158	−0.397	0.4507
3	1.118	1.153	−0.193	0.4467
4	1.117	1.149	0.000	0.4473
5	1.127	1.149	+0.196	0.4414
6	1.130	1.148	+0.293	0.4378
7	1.142	1.157	+0.390	0.4346
8	1.146	1.150	+0.487	0.4294
9	1.142	1.147	+0.493	0.4304
10	1.156	1.152	+0.588	0.4251
11	1.158	1.150	+0.593	0.4227
12	1.172	1.151	+0.688	0.4158
13	1.174	1.154	+0.690	0.4158
14	1.211	1.150	+0.788	0.3955
15	1.279	1.153	+0.881	0.3653

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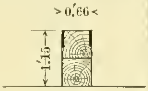
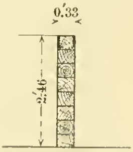
(1)	(2)	(3)	(4)	(5)
16	1.335	1.151	+0.984	0.3420
1	1.243	1.312	—0.394	0.4644
2	1.252	1.317	—0.198	0.4620
3	1.253	1.316	—0.002	0.4615
4	1.259	1.313	+0.195	0.4561
5	1.269	1.308	+0.597	0.4481
6	1.274	1.308	+0.490	0.4451
7	1.288	1.312	+0.590	0.4405
8	1.304	1.317	+0.687	0.4322
9	1.306	1.315	+0.689	0.4201
10	1.326	1.314	+0.784	0.4345
11	1.332	1.315	+0.785	0.4220
12	1.397	1.314	+0.889	0.3907
13	1.446	1.320	+0.985	0.3734
1	1.376	1.479	—0.390	0.4787
2	1.382	1.478	—0.200	0.4753
3	1.396	1.491	+0.001	0.4746
4	1.395	1.479	+0.197	0.4688
5	1.400	1.474	+0.396	0.4635
6	1.423	1.479	+0.589	0.4555
7	1.461	1.480	+0.780	0.4381

Bazin's Series
No. 121.



(1)	(2)	(3)	(4)	(5)
1	0.386	0.328	—0.193	0.3395
2	0.387	0.329	—0.096	0.3395
3	0.388	0.329	+0.041	0.3383
4	0.388	0.330	+0.086	0.3398
5	0.389	0.331	+0.183	0.3391
6	0.395	0.329	+0.271	0.3295
7	0.423	0.328	+0.371	0.2963
8	0.496	0.325	+0.460	0.2288
9	0.581	0.333	+0.564	0.1883
10	0.667	0.331	+0.655	0.1516
1	0.538	0.495	—0.462	0.3760
2	0.542	0.492	—0.374	0.3714
3	0.546	0.493	—0.187	0.3681
4	0.547	0.492	—0.001	0.3665
5	0.550	0.493	+0.087	0.3632
6	0.550	0.495	+0.184	0.3653
7	0.555	0.494	+0.273	0.3604
8	0.562	0.494	+0.369	0.3532
9	0.579	0.494	+0.455	0.3383
10	0.624	0.493	+0.557	0.2999
11	0.709	0.494	+0.647	0.2492
12	0.780	0.494	+0.735	0.2158
	0.689	0.660	—0.175	0.3987
	0.690	0.661	—0.001	0.3993
3	0.699	0.661	+0.184	0.3917
4	0.701	0.659	+0.281	0.3878
5	0.711	0.660	+0.370	0.3809
6	0.716	0.659	+0.459	0.3758
7	0.732	0.658	+0.561	0.3635
8	0.768	0.661	+0.649	0.3405
9	0.841	0.661	+0.742	0.2969
10	0.911	0.657	+0.833	0.2605
11	0.988	0.658	+0.929	0.2308
1	0.829	0.824	+0.001	0.4219
2	0.839	0.825	+0.181	0.4147
3	0.839	0.822	+0.281	0.4127
4	0.847	0.829	+0.368	0.4111
5	0.852	0.828	+0.458	0.4076
6	0.863	0.827	+0.557	0.3992
7	0.871	0.828	+0.618	0.3934
8	0.875	0.819	+0 654	0.3852
9	0.906	0.825	+0.732	0.3700
10	0.975	0.828	+0.832	0.3322
11	1.040	0.823	+0.923	0.2994
12	1.112	0.823	+1.020	0.2710
13	1.189	0.826	+1.112	0.2455
1	0.961	0.986	+0.178	0.4432
2	0.968	0.991	+0.281	0.4400
3	0.967	0.986	+0.375	0.4377
4	0.979	0.987	+0.463	0.4315
5	0.986	0.987	+0.558	0.4269
6	1.001	0.988	+0.652	0.4173
7	1.020	0.989	+0.744	0.4067
8	1.019	0.989	+0.745	9.4073
9	1.047	0.985	+0.829	0.3894
10	1.113	0.992	+0.923	0.3583
11	1.177	0.989	+1.017	0.3289
12	1.248	0.989	+1.113	0.3007
13	1.314	0.984	+1.205	0.2760
1	1.093	1.147	+0.281	0.4597
2	1.100	1.150	+0.368	0.4569
3	1.105	1.151	+0.464	0.4544
4	1.115	1.152	+0.554	0.4489
5	1.121	1.150	+0.654	0.4439
6	1.134	1.151	+0.736	0.4368
7	1.158	1.152	+0.828	0.4235
8	1.168	1.147	+0.876	0.4154
9	1.187	1.150	+0.925	0.4054
10	1.255	1.150	+1.018	0.3751
11	1.315	1.151	+1.113	0.3493
12	1.381	1.151	+1.204	0.3249
13	1.439	1.149	+1.293	0.3051
1	1.230	1.317	+0.462	0.4742
2	1.237	1.316	+0.557	0.4693
3	1.242	1.314	+0.653	0.4654
4	1.257	1.315	+0.743	0.4586
5	1.268	1.309	+0.834	0.4484
6	1.294	1.311	+0.923	0.4358
7	1.344	1.311	+1.020	0.4126
8	1.371	1.316	+1.063	0.4024
9	1.398	1.312	+1.115	0.3890
10	1.453	1.314	+1.204	0.3684
11	1.509	1.315	+1.294	0.3479
1	1.336	1.478	+0.659	0.4995
2	1.376	1.474	+0.747	0.4763
3	1.395	1.485	+0.829	0.4721
4	1.405	1.477	+0.922	0.4628
5	1.441	1.476	+1.024	0.4447
6	1.495	1.478	+1.114	0.4222
7	1.542	1.478	+1.203	0.4029
8	1.587	1.477	+1.292	0.3861

Bazin's Series
No. 122.



(1)	(2)	(3)	(4)	(5)
1	0.360	0.330	—0.187	0.3792
2	0.353	0.322	—0.098	0.3780
3	0.361	9.328	0.000	0.3755
4	0.371	0.330	+0.095	0.3639
5	0.372	0.327	+0.192	0.3571
6	0.376	0.337	+0.294	0.3681
1	0.495	0.502	—0.381	0.4354
2	0.495	0.489	—0.198	0.4187
3	0.504	0.494	—0.002	0.4155
4	0.515	0.495	+0.198	0 4036

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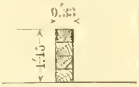
(1)	(2)	(3)	(4)	(5)
5	0.523	0.493	+0.293	0.3923
6	0.579	0.492	+0.390	0.3352
7	0.756	0.494	+0.488	0.2259
1	0.631	0.658	—0.401	0.4529
2	0.634	0.658	—0.199	0.4505
3	0.640	0.657	0.000	0.4476
4	0.644	0.650	+0.197	0.4324
5	0.654	0.654	+0.292	0.4251
6	0.718	0.655	+0.396	0.3713
7	0.808	0.658	+0.596	0.3130
1	0.751	0.813	—0.590	0.4805
2	0.768	0.824	—0.393	0.4734
3	0.766	0.821	—0.199	0.4733
4	0.771	0.819	+0.002	0.4667
5	0.779	0.813	+0.196	0.4543
6	0.841	0.823	+0.299	0.4126
7	0.853	0.812	+0.387	0.3959
8	0.887	0.817	+0.489	0.3758
8	0.931	0.823	+0.592	0.3541
10	1.016	0.815	+0.784	0.3059
1	0.880	0.987	—0.791	0.5064
2	0.879	0.980	—0.589	0.5117
3	0.884	0.983	—0.411	0.5001
4	0.890	0.991	—0.398	0.5010
5	0.889	0.982	—0.199	0.4946
6	0.897	0.978	—0.001	0.4859
7	0.912	0.986	+0.095	0.4792
8	0.960	0.983	+0.196	0.4412
9	0.984	0.986	+0.291	0.4279
10	1.006	0.983	+0.391	0.4114
11	1.027	0.983	+0.490	0.3991
12	1.059	0.978	+0.587	0.3784
13	1.099	0.986	+0.647	0.3624
14	1.135	0.984	+0.784	0.3447
15	1.231	0.985	+0.977	0.3048
1	1.009	1.150	—0.585	0.5214
2	1.012	1.147	—0.408	0.5150
3	1.021	1.148	—0.201	0.5118
4	1.077	1.151	+0.001	0.4722
5	1.118	1.149	+0.192	0.4453
6	1.152	1.147	+0.388	·0.4227
7	1.206	1.151	+0.585	0.3983
8	1.234	1.149	+0.688	0.3839
9	1.264	1.152	+0.783	0.3715
10	1.344	1.149	+0.980	0.3374
1	1.144	1.307	—0.401	0.5221
2	1.202	1.313	—0.201	0.4892
3	1.242	1.311	—0.006	0.4644
4	1.270	1.312	+0.255	0.4497
5	1.303	1.312	+0.387	0.4322
6	1.354	1.312	+0.595	0.4087
1	1.348	1.479	—0.395	0.4931
2	1.370	1.479	—0.192	0.4819
3	1.393	1.476	+0.004	0.4683

Series No. 122.



(1)	(2)	(3)	(4)	(5)
1	0.355	0.331	—0.282	0.3885
2	0.358	0.330	—0.188	0.3845
3	0.354	0.327	—0.092	0.3827
4	0.362	0.329	+0.003	0.3758
5	0.361	0.327	+0.094	0.3729
6	0.370	0.331	+0.180	0.3654
7	0.382	0.327	+0.279	0.3420
8	0.438	0.330	+0.365	0.2792
1	0.496	0.502	—0.373	0.4339
2	0.494	0.494	—0.284	0.4278
3	0.496	0.500	—0.184	0.4302
4	0.497	0.499	—0.091	0.4277
5	0.496	0.494	+0.005	0·4235
6	0.505	0.494	+0.095	0.4153
7	0.505	0.493	+0.181	0.4128
8	0.516	0.499	+0.280	0.4054
9	0.537	0.503	+0.370	0.3866
10	0.599	0.501	+0.466	0.3269
11	0.655	0.496	+0.561	0.2813
12	0.721	0.501	+0.649	0.2470
1	0.622	0.658	—0.181	0.4611
2	0.632	0.666	—0.091	0.4595
3	0.627	0.658	—0.002	0.4547
4	0.639	0.663	+0.090	0.4488
5	0.634	0.657	+0.179	0.4480
6	0.641	0.657	+0.269	0.4408
7	0.657	0.657	+0.368	0.4244
8	0.707	0.658	+0.467	0.3822
9	0.756	0.658	+0.557	0 3460
10	0.806	0.665	+0.650	0.3190
11	0.861	0.662	+0.740	0.2863
1	0.755	0.822	+0.001	0.4827
2	0.762	0.823	+0.097	0.4776
3	0.760	0.819	+0.196	0.4749
4	0.766	0.818	+0.272	0.4688
5	0.782	0.822	+0.368	0.4579
6	0.832	0.819	+0.469	0.4157
7	0.869	0.824	+0.559	0.3922
8	0.902	0.825	+0.649	0.3716
9	0.948	0.825	+0.742	0.3449
10	0.998	0.817	+0.843	0.3141
11	1.060	0.825	+0.928	0.2918
1	0.884	0.987	+0.182	0.5018
2	0.894	0.993	+0.277	0.4967
3	0.923	0.987	+0.369	0.4708
4	0.959	0.981	+0.462	0.4401
5	0.993	0.995	+0.557	0.4263
6	1.018	0.986	+0.648	0.4048
7	1.059	0.995	+0.740	0.3878
8	1.090	0.984	+0.838	0.3635
9	1.134	0.983	+0.922	0.3435
10	1.186	0.984	+1.016	0.3211
1	1.068	1.153	+0.365	0.4783
2	1.100	1.149	+0.466	0.4549
3	1.123	1.158	+0.557	0.4471
4	1.141	1.150	+0.651	0.4315
5	1.177	1.154	+0.743	0.4137
6	1.205	1.152	+0.839	0.3984
7	1.236	1.155	+0.923	0.3850
8	1.283	1.157	+1.018	0.3646
9	1.321	1.148	+1.112	0.3450
10	1.387	1.152	+1.208	0.3225
1	1.248	1.314	+0.559	0.4619
2	1.269	1.317	+0.653	0.4520
3	1.290	1.314	+0.746	0.4388
4	1.318	1.317	+0.835	0.4268
5	1.347	1.317	+0.923	0.4130
6	1.387	1.315	+1.021	0.3940
7	1.423	1.315	+1.110	0.3870
8	1.475	1.324	+1.203	0.3640
1	1.406	1.480	+0.655	0.4632
2	1.417	1.481	+0.745	0.4581
3	1.444	1.478	+0.831	0.4444
4	1.465	1.483	+0.926	0.4365
5	1.498	1.479	+1.018	0.4204
6	1.526	1.478	+1.110	0.4085
7	1.572	1.477	+1.202	0.3909

Mr. Nelles.

BAZIN'S EXPERIMENTS.—TABLE SHOWING THE HEADS CORRESPONDING TO THE SAME DISCHARGE OVER THE FOUR WEIRS JUST CONSIDERED, FOR VARIOUS ELEVATIONS OF THE SURFACE OF THE WATER RETAINED BELOW THE WEIR.

A denotes weir 0.75 m. = 2.46 ft. high; with crest 0.20 m. = 0.66 ft. wide.
B " " 0.35 m. = 1.15 " " " " 0.20 m. = 0.66 " "
C denotes weir 0.75 m. = 2.46 ft. high; with crest 0.10 m. = 0.33 ft. wide.
D " " 0.35 m. = 1.15 " " " " 0.10 m. = 0.33 " "

(1) Head on the standard weir of comparison (H) in feet.	(2) Description of weir under consideration.	(3) Head on similar weir when flow is not affected by water below.	Head, in Feet, on the Weirs under Consideration. Height of the water surface below the weirs, above the level of the crest h_1.													Remarks.
			0	0.098	0.197	0.295	0.394	0.492	0.591	0.689	0.787	0.886	0.984	1.083	1.181	
0.328.....	*A*	0.387	0.391	0.391	0.394	0.404	0.443	0.542	.....	.....	.....	.....	.....	.....	.....	The nappe was detached from the crest when head became about 0.4 ft.
	B	0.384	0.387	0.391	0.414	0.404	0.439	0.509	.....	.....	.....	.....	.....	.....	.....	
	C	0.358	0.361	0.394	0.371	0.384	0.456	0.456	.....	.....	.....	.....	.....	.....	.....	
	D	0.351	0.361	0.364	0.371	0.387	0.446	0.446	.....	.....	.....	.....	.....	.....	.....	
0.492.....	*A*	0.548	0.551	0.558	0.561	0.568	0.578	0.608	0.676	0.787	.....	.....	.....	.....	.....	The nappe was detached from crest when the head became about 0.53 ft.
	B	0.548	0.551	0.551	0.555	0.558	0.568	0.598	0.659	0.742	.....	.....	.....	.....	.....	
	C	0.499	0.502	0.509	0.518	0.532	0.598	0.598	0.598	0.598	.....	.....	.....	.....	.....	
	D	0.479	0.495	0.499	0.509	0.522	0.551	0.626	0.676	0.676	.....	.....	.....	.....	.....	
0.656.....	*A*	0.699	0.709	0.715	0.719	0.725	0.732	0.745	0.765	0.830	0.919	0.919	.....	.....	.....	The nappe was detached from the crest when the head became about 0.7 ft.
	B	0.689	0.689	0.692	0.699	0.706	0.709	0.719	0.745	0.794	0.866	0.948	.....	.....	.....	
	C	0.630	0.636	0.643	0.653	0.666	0.719	0.762	0.810	0.856	0.856	0.856	.....	.....	.....	
	D	0.614	0.626	0.633	0.636	0.643	0.673	0.715	0.768	0.820	0.820	0.820	.....	.....	.....	
0.820.....	*A*	0.830	0.853	0.856	0.859	0.866	0.876	0.883	0.896	0.926	0.981	1.060	1.145	1.145	.....	The nappe was detached from the crest when the head became about 0.8 ft.
	B	0.827	0.830	0.833	0.837	0.840	0.843	0.850	0.869	0.889	0.945	1.014	1.083	1.174	.....	
	C	0.752	0.775	0.784	0.794	0.817	0.850	0.893	0.929	0.977	1.027	1.027	1.027	1.027	.....	
	D	0.745	0.752	0.758	0.762	0.772	0.797	0.833	0.873	0.916	0.971	1.027	1.027	1.027	.....	
0.984.....	*A*	0.964	0.987	0.991	0.994	1.000	1.007	1.014	1.027	1.047	1.103	1.168	1.227	1.292	1.355	The nappe was detached from the crest when the head became about 0.95 ft.
	B	0.958	0.958	0.958	0.961	0.964	0.971	0.981	0.991	1.014	1.033	1.086	1.151	1.224	1.299	
	C	0.879	0.906	0.926	0.954	0.977	1.004	1.033	1.063	1.103	1.145	1.188	1.237	1.237	1.237	
	D	0.873	0.873	0.886	0.886	0.896	0.932	0.945	1.000	1.041	1.086	1.132	1.171	1.224	1.224	
1.148.....	*A*	1.099	1.119	1.126	1.129	1.132	1.142	1.145	1.161	1.178	1.214	1.276	1.324	1.414	1.414	The nappe was detached from the crest when the head became about 1.1 ft.
	B	1.096	1.096	1.096	1.096	1.096	1.099	1.109	1.116	1.129	1.145	1.174	1.227	1.289	1.361	
	C	1.017	1.083	1.093	1.116	1.136	1.151	1.178	1.207	1.234	1.267	1.309	1.355	1.355	1.355	
	D	1.080	1.080	1.080	1.080	1.080	1.073	1.099	1.126	1.155	1.184	1.221	1.257	1.302	1.361	
1.312.....	*A*	1.230	1.254	1.257	1.260	1.267	1.270	1.279	1.292	1.305	1.332	1.381	1.451	1.451	1.451	The nappe was detached from the crest when the head became about 1.2 ft.
	B	1.224	1.224	1.224	1.224	1.224	1.224	1.230	1.244	1.250	1.263	1.286	1.325	1.381	1.441	
	C	1.155	1.240	1.257	1.276	1.289	1.309	1.328	1.355	1.371	1.401	1.444	1.476	1.476	1.476	
	D	1.221	1.221	1.221	1.221	1.221	1.221	1.234	1.251	1.279	1.302	1.335	1.368	1.408	1.457	

Mr. Nelles. "In the experiments with weirs in thin partition, we have had recourse to Equations 11 and 12" (page 270), "to deduce the value of the coefficient *m*, but the presence of the sill introduces such complications that these equations are no longer perfectly applicable. The constants, which appear in the equations, vary so greatly with the head and width of crest, that it becomes impossible to establish a simple and practical formula.

"We must, therefore, content ourselves with a general *résumé* in a table showing the heads on the four weirs under consideration, corresponding to constant discharges and varying elevation of the water surface below the weirs. The corresponding head, where the flow is not affected by the retained water, is also shown."

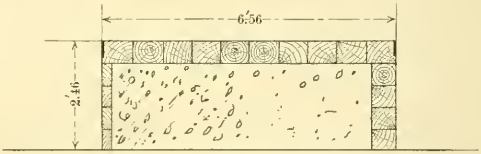
"We see that for the same discharge the heads vary notably from one weir to the other. The question is singularly complicated by the detachment of the nappe, which leaves the sill when the head attains certain limits depending on the width of the crest. The head and coefficient are then modified suddenly. This limit depends on the height of the retained water, and is not the same, even under fixed conditions. We cannot therefore, establish as precise formulas as in the more simple case of the flow over weirs in thin partition."

BAZIN'S EXPERIMENTS.—SERIES No. 124.

Nappe wetted underneath, with water retained in pool below weir. Height of weir under observation, 0.75 m. = 2.46 ft. Width of crest, 2.0 m. = 6.56 ft. Length, 2.0 m. = 6.56 ft.

Height of standard weir of comparison, 0.75 m. = 2.46 ft. Length, 2.0 m. = 6.56 ft.

Bazin's Series No. 124.



(1)	(2)	(3)	(4)	(5)
1	0.398	0.325	+0.098	0.3199
2	0.403	0.330	+0.197	0.3227
3	0.399	0.325	+0.299	0.3187
4	0.451	0.328	+0.394	0.2678
5	0.526	0.326	+0.491	0.2111
1	0.598	0.494	+0.295	0.3228
2	0.590	0.492	+0.393	0.3264
3	0.609	0.492	+0.496	0.3114
4	0.668	0.490	+0.594	0.2684
5	0.748	0.489	+0.686	0.2263
1	0.777	0.655	+0.447	0.3301
2	0.781	0.657	+0.603	0.3288
3	0.811	0.656	+0.691	0.3099
4	0.890	0.658	+0.796	0.2709
5	0.961	0.660	+0.890	0.2422
1	0.961	0.815	+0.593	0.2325
2	0.966	0.814	+0.692	0.3289
3	0.971	0.820	+0.792	0.3299
4	1.024	0.817	+0.890	0.3034
5	1.094	0.814	+0.989	0.2736
6	1.170	0.812	+1.084	0.2462
1	1.158	0.990	+0.794	0.3364
2	1.157	0.986	+0.895	0.3355
3	1.180	0.991	+0.993	0.3266
4	1.232	0.985	+1.091	0.3048
5	1.298	0.981	+1.183	0.2798
1	1.343	1.148	+0.985	0.3379
2	1.352	1.149	+1.078	0.3351
3	1.370	1.148	+1.180	0.2277
4	1.441	1.149	+1.276	0.3043

In his 6th and last article Bazin discusses the flow over submerged weirs, with sloping faces and crests of different widths and forms, and gives the results of 11 series, consisting of 724 individual observations. The methods used were similar to those already described for weirs of squared timbers (beam weirs). Bazin says of these experiments: Mr. Nelles.

"It now remains to terminate that which concerns the flow over weirs with sloping faces by describing the experiments made with water retained below the weirs.

"They form 11 series, three on weirs with sharp crest, seven on weirs with crest 0.20 m. (0.66 ft.) wide, one on weirs with crest 0.40 m. (1.32 ft.) wide."

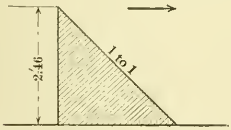
BAZIN'S EXPERIMENTS.—SERIES NOS. 195 TO 197.

Nappe wetted underneath, with water retained in pool below weir.

Description of weirs under observation: Height, 0.75 m. = 2.46 ft. Length, 2.0 m. = 6.56 ft. Crest sharp. Upper face vertical, lower face sloping.

Dimensions of standard weir used for measuring the discharge: Height, 1.135 m. = 3.72 ft. Length, 2.0 m. = 6.56 ft.

Bazin's Series No. 195.

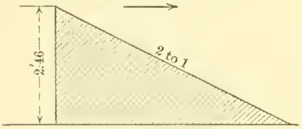


(1)	(2)	(3)	(4)	(5)
Number of experiment.	OBSERVED HEADS IN FEET.		Height of the retained water with reference to crest. + = above. − = below. (*h*)	COEFFICIENTS OF DISCHARGE.
	On the weir under consideration. (*h*)	On the standard weir of comparison. (*H*)		For the Bazin formula. (*m*)
1	0.308	0.331	−0.196	0.4785
2	0.318	0.326	+0.007	0.4482
3	0.337	0.328	+0.103	0.4163
4	0.383	0.331	+0.198	0.3492
5	0.419	0.331	+0.296	0.3046
1	0.452	0.490	−0.396	0.4808
2	0.461	0.493	−0.194	0.4726
3	0.465	0.489	−0.004	0.4612
4	0.488	0.491	+0.100	0.4315
5	0.510	0.497	+0.198	0.4131
6	0.533	0.495	+0.199	0.3830
7	0.556	0.500	+0.297	0.3655
8	0.594	0.490	+0.403	0.3216
1	0.605	0.654	−0.592	0.4800
2	0.600	0.653	−0.391	0.4842
3	0.610	0.654	−0.200	0.4746
4	0.620	0.654	+0.006	0.4619
5	0.634	0.660	+0.098	0.4526
6	0.650	0.653	+0.203	0.4288
7	0.674	0.654	+0.294	0.4077
8	0.702	0.660	+0.297	0.3886
9	0.732	0.656	+0.403	0.3617
10	0.806	0.656	+0.591	0.3130
1	0.743	0.819	−0.743	0.4917
2	0.750	0.817	−0.393	0.4837
3	0.746	0.817	−0.196	0.4873
4	0.758	0.812	−0.002	0.4722
5	0.792	0.815	+0.198	0.4442
6	0.844	0.815	+0.295	0.4041
7	0.863	0.813	+0.392	0.3897
8	0.930	0.814	+0.593	0.3489
9	1.024	0.818	+0.789	0.3041
1	0.885	0.976	−0.788	0.4946
2	0.886	0.973	−0.385	0.4906
3	0.901	0.988	−0.199	0.4905
4	0.908	0.979	+0.002	0.4783
5	0.941	0.984	+0.208	0.4567
6	1.016	0.982	+0.402	0.4048

Mr. Nelles.

(1)	(2)	(3)	(4)	(5)
7	1.021	0.983	+0.402	0.4022
8	1.070	0.978	+0.600	0.3734
9	1.144	0.982	+0.795	0.3390
10	1.241	0.986	+0.986	0.3019
1	1.042	1.147	−0.582	0.4935
2	1.041	1.148	−0.389	0.4944
3	1.051	1.156	−0.197	0.4931
4	1.058	1.150	0.000	0.4848
5	1.095	1.152	+0.208	0.4614
6	1.171	1.149	+0.406	0.4154
7	1.210	1.144	+0.593	0.3919
8	1.217	1.146	+0.599	0.3904
9	1.280	1.156	+0.792	0.3664
10	1.355	1.149	+0.786	0.3336
1	1.189	1.317	−0.396	0.4994
2	1.190	1.311	−0.195	0.4958
3	1.226	1.313	+0.004	0.4753
4	1.242	1.313	+0.197	0.4658
5	1.309	1.307	+0.393	0.4274
6	1.358	1.312	+0.598	0.4070
7	1.412	1.314	+0.790	0.3847
1	1.336	1.474	−0.192	0.4970
2	1.345	1.475	+0.004	0.4926
3	1.409	1.474	+0.204	0.4599
4	1.449	1.467	+0.388	0.4371

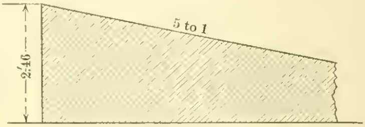
Bazin's Series No. 196.



1	0.327	0.326	−0.200	0.4312
2	0.328	0.325	−0.006	0.4286
3	0.342	0.326	+0.097	0.4036
4	0.360	0.323	+0.199	0.3702
5	0.407	0.330	+0.289	0.3167
6	0.468	0.323	+0.392	0.2186
1	0.484	0.486	−0.200	0.4319
2	0.485	0.491	−0.001	0.4353
3	0.495	0.491	+0.097	0.4227
4	0.507	0.492	+0.189	0.4081
5	0.533	0.487	+0.292	0.3753
6	0.570	0.491	+0.392	0.3423
7	0.637	0.487	+0.493	0.2857
1	0.642	0.556	+0.001	0.4364
2	0.655	0.649	+0.194	0.4202
3	0.664	0.654	+0.207	0.4162
4	0.680	0.653	+0.296	0.4004
5	0.700	0.653	+0.395	0.3838
6	0.743	0.659	+0.492	0.3558
7	0.801	0.654	+0.599	0.3138
8	0.865	0.657	+0.688	0.2816
1	0.804	0.819	0.000	0.4371
2	0.812	0.819	+0.197	0.4316
3	0.824	0.820	+0.287	0.4215
4	0.841	0.817	+0.385	0.4078
5	0.873	0.818	+0.491	0.3863
6	0.902	0.819	+0.580	0.3676
7	0.982	0.820	+0.693	0.3240
8	1.029	0.819	+0.781	0.3020
1	0.964	0.985	+0.198	0.4414
2	0.985	0.982	+0.392	0.4235
3	1.005	0.985	+0.493	0.4126
4	1.029	0.981	+0.586	0.3963
5	1.065	0.984	+0.691	0.3789

(1)	(2)	(3)	(4)	(5)
6	1.146	0.983	+0.785	0.3383
7	1.196	0.983	+0.886	0.3175
8	1.239	0.981	+0.983	0.2998
1	1.119	1.152	+0.195	0.4460
2	1.131	1.150	+0.386	0.4374
3	1.147	1.143	+0.490	0.4248
4	1.164	1.146	+0.594	0.4153
5	1.199	1.146	+0.697	0.3986
6	1.230	1.149	+0.789	0.3851
7	1.287	1.150	+0.893	0.3631
8	1.358	1.147	+0.980	0.3322
9	1.414	1.153	+1.091	0.3144
1	1.281	1.313	+0.389	0.4443
2	1.311	1.311	+0.557	0.4284
3	1.330	1.306	+0.682	0.4165
4	1.357	1.311	+0.783	0.4065
5	1.390	1.313	+0.880	0.3928
6	1.434	1.314	+0.977	0.3757

Bazin's Series No. 197.

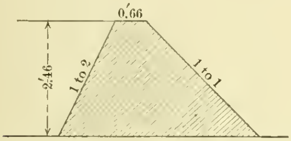


1	0.355	0.325	+0.195	0.3793
2	0.384	0.325	+0.295	0.3373
3	0.454	0.326	+0.397	0.2630
4	0.595	0.327	+0.494	0.2102
1	0.527	0.491	+0.294	0.3859
2	0.552	0.494	+0.397	0.3620
3	0.595	0.491	+0.493	0.3210
4	0.675	0.491	+0.594	0.2655
5	0.751	0.490	+0.691	0.2268
1	0.698	0.655	+0.403	0.3876
2	0.711	0.655	+0.494	0.3756
3	0.750	0.652	+0.589	0.3413
4	0.792	0.653	+0.694	0.3185
5	0.894	0.653	+0.795	0.2663
6	0.967	0.655	+0.887	0.2369
1	0.862	0.815	+0.494	0.3919
2	0.876	0.812	+0.563	0.3807
3	0.910	0.812	+0.693	0.3594
4	0.956	0.810	+0.791	0.3317
5	1.018	0.818	+0.888	0.3067
6	1.047	0.809	+0.993	0.2639
7	1.192	0.815	+1.092	0.2409
1	1.038	0.985	+0.600	0.3946
2	1.042	0.976	+0.690	0.3874
3	1.077	0.986	+0.792	0.3741
4	1.113	0.977	+0.885	0.3513
5	1.170	0.983	+0.988	0.3278
6	1.251	0.981	+1.084	0.2967
7	1.323	0.986	+1.176	0.2744
1	1.216	1.149	+0.792	0.3921
2	1.232	1.172	+0.882	0.3798
3	1.278	1.146	+0.995	0.3622
4	1.326	1.145	+1.091	0.3424
5	1.372	1.146	+1.180	0.3256
6	1.460	1.146	+1.279	0.2962
1	1.374	1.303	+0.882	0.3956
2	1.404	1.311	+0.985	0.3861
3	1.429	1.304	+1.082	0.3735
4	1.478	1.311	+1.182	0.3563

BAZIN'S EXPERIMENTS.—SERIES NOS. 198 TO 208.

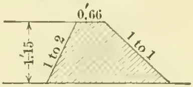
Nappe wetted underneath, with water retained in pool below weir. Description of weirs under observation: Height 0.75 m. = 2.46 ft. 0.35 m. = 1.15 ft. Length 2.0 m. = 6.56 ft. Crest 0.20 m. = 0.66 ft. wide. Upper and lower faces inclined.

Bazin's Series No. 198.



(1)	(2)	(3)	(4)	(5)
1	0.370	0.327	+0.098	0.3602
2	0.380	0.334	+0.144	0.3549
3	0.379	0.336	+0.147	0.3600
4	0.376	0.328	+0.197	0.3529
5	0.383	0.326	+0.295	0.3402
6	0.431	0.328	+0.394	0.2856
7	0.520	0.328	+0.492	0.2156
1	0.543	0.497	+0.197	0.3757
2	0.536	0.496	+0.198	0.3804
3	0.539	0.495	+0.240	0.3758
4	0.553	0.501	+0.289	0.3650
5	0.559	0.495	+0.403	0.3559
6	0.590	0.496	+0.492	0.3305
7	0.671	0.492	+0.592	0.2743
1	0.682	0.656	+0.198	0.4007
2	0.711	0.660	+0.395	0.3802
3	0.691	0.657	+0.397	0.3933
4	0.698	0.656	+0.438	0.3872
5	0.723	0.661	+0.509	0.3717
6	0.743	0.658	+0.589	0.3546
7	0.806	0.655	+0.687	0.3115
8	0.895	0.657	+0.789	0.2675
9	0.973	0.659	+0.888	0.2372
1	0.822	0.823	+0.299	0.4231
2	0.831	0.819	+0.395	0.4161
3	0.854	0.823	+0.488	0.4018
4	0.839	0.818	+0.491	0.4088
5	0.864	0.824	+0.543	0.3962
6	0.845	0.822	+0.544	0.4074
7	0.868	0.818	+0.591	0.3888
8	0.858	0.822	+0.592	0.3982
9	0.888	0.818	+0.686	0.3756
10	0.963	0.820	+0.788	0.3331
11	1.035	0.823	+0.879	0.3015
12	1.115	0.822	+0.994	0.2694
1	0.954	0.981	+0.300	0.4432
2	0.954	0.976	+0.395	0.4401
3	0.962	0.980	+0.490	0.4369
4	0.973	0.986	+0.592	0.4335
5	0.995	0.982	+0.598	0.4174
6	0.985	0.987	+0.635	0.4266
7	1.011	0.986	+0.692	0.4103
8	1.039	0.985	+0.789	0.3929
9	1.119	0.988	+0.884	0.3536
10	1.196	0.985	+0.983	0.3179
11	1.192	0.985	+0.991	0.3193
12	1.258	0.989	+1.083	0.2969
1	1.092	1.148	+0.397	0.4601
2	1.092	1.144	+0.496	0.4575
3	1.105	1.149	+0.593	0.4523
4	1.115	1.148	+0.689	0.4458
5	1.137	1.144	+0.691	0.4307
6	1.131	1.147	+0.745	0.4355
7	1.150	1.148	+0.788	0.4231
8	1.189	1.149	+0.884	0.4057
9	1.281	1.148	+0.979	0.3612
10	1.354	1.146	+1.087	0.3378
11	1.410	1.148	+1.182	0.3131
1	1.226	1.312	+0 494	0.4738
2	1.227	1.310	+0.593	0.4714
3	1.239	1.313	+0.689	0.4664
4	1.268	1.311	+0.740	0.4501
5	1.248	1.313	+0.741	0.4620
6	1.281	1.313	+0.785	0.4433
7	1.259	1.311	+0.786	0.4541
8	1.288	1.310	+0.835	0.4383
9	1.291	1.316	+0.841	0.4397
10	1.306	1.314	+0.888	0.4314
11	1.373	1.314	+0.983	0.4001
12	1.327	1.309	+1.083	0.3685
1	1.362	1.475	+0.594	0.4816
2	1.376	1.471	+0.784	0.4744
3	1.424	1.477	+0.887	0.4529
4	1.418	1.476	+0.887	0.4560

Bazin's Series No. 199.

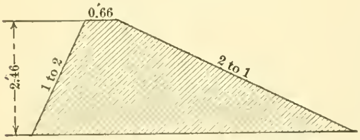


(1)	(2)	(3)	(4)	(5)
1	0.375	0.327	—0.190	0.3516
2	0.376	0.331	+0.001	0.3560
3	0.378	0.327	+0.178	0.3474
4	0.380	0.326	+0.276	0.3446
5	0.419	0.330	+0.376	0.3053
6	0.491	0.320	+0.460	0.2300
7	0.581	0.332	+0.561	0.1868
1	0.536	0.500	+0.002	0.3855
2	0.535	0.493	+0.164	0.3779
3	0.537	0.497	+0.273	0.3800
4	0.557	0.501	+0.366	0.3665
5	0.566	0.490	+0.460	0.3453
6	0.622	0.495	+0.565	0.3031
7	0.696	0.493	+0.649	0.2552
1	0.670	0.655	+0.002	0.4101
2	0.676	0.656	+0.176	0.4060
3	0.674	0 656	+0.273	0.4084
4	0.688	0.656	+0.373	0.3950
5	0.697	0.651	+0.466	0.3842
6	0.726	0.656	+0.561	0.3651
7	0.748	0.656	+0.644	0.3491

Mr. Nelles.

(1)	(2)	(3)	(4)	(5)
8	0.824	0.657	+0.742	0.3023
9	0.903	0.655	+0.838	0.2627
10	0.989	0.660	+0.933	0.2314
1	0.806	0.821	+0.095	0.4370
2	0.799	0.811	+0.271	0.4344
3	0.809	0.810	+0.367	0.4259
4	0.827	0.821	+0.464	0.4202
5	0.834	0.823	+0.504	0.4161
6	0.839	0.821	+0.519	0.4103
7	0.848	0.820	+0.568	0.4035
8	0.855	0.815	+0.681	0.3949
9	0.880	0.813	+0.736	0.3771
10	0.947	0.817	+0.837	0.3401
11	1.018	0.811	+0.923	0.3019
12	1.094	0.814	+1.013	0.2725
1	0.932	0.983	+0.279	0.4608
2	0.941	0.985	+0.367	0.4557
3	0.944	0.980	+0.465	0.4495
4	0.960	0.980	+0.557	0.4382
5	0.976	0.981	+0.646	0.4281
6	0.993	0.976	+0.740	0.4153
7	1.019	0.979	+0.837	0.4003
8	1.082	0.978	+0.932	0.3659
9	1.146	0.976	+1.016	0.3350
10	1.220	0.979	+1.108	0.3057
11	1.305	0.978	+1.212	0.2758
1	1.061	1.150	+0.370	0.4789
2	1.070	1.147	+0.461	0.4731
3	1.085	1.159	+0.517	0.4710
4	1.080	1.147	+0.555	0.4668
5	1.098	1.149	+0.653	0.4559
6	1.111	1.149	+0.735	0.4480
7	1.135	1.150	+0.835	0.4347
8	1.154	1.151	+0.921	0.4357
9	1.200	1.143	+1.015	0.3955
10	1.274	1.146	+1.108	0.3636
11	1.360	1.150	+1.208	0.3316
1	1.190	1.309	+0.461	0.4934
2	1.209	1.318	+0.563	0.4865
3	1.213	1.305	+0.647	0.4770
4	1.223	1.293	+0.749	0.4648
5	1.253	1.314	+0.842	0.4594
6	1.272	1.316	+0.934	0.4499
7	1.294	1.315	+1.012	0.4426
8	1.341	1.320	+1.113	0.4172
9	1.420	1.311	+1.206	0.3792
1	1.339	1.469	+0.655	0.4970
2	1.349	1.478	+0.736	0.4911
3	1.355	1.475	+0.837	0.4859
4	1.373	1.475	+0.917	0.4765
5	1.389	1.474	+1.019	0.4679
6	1.419	1.476	+1.115	0.4545
7	1.474	1.476	+1.205	0.4298
8	1.531	1.472	+1.291	0.4036

Bazin's Series No. 200.

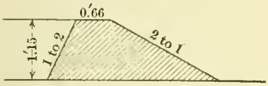


(1)	(2)	(3)	(4)	(5)
1	0.386	0.335	+0.093	0.3480
2	0.385	0.330	+0.189	0.3461
3	0.387	0.334	+0.234	0.3456
4	0.383	0.329	+0.235	0.3448
5	0.387	0.329	+0.282	0.3382
6	0.392	0.526	+0.292	0.3278
7	0.405	0.331	+0.331	0.3202
8	0.437	0.832	+0.391	0.2850
9	0.518	0.326	+0.493	0.2146
10	0.616	0.330	+0.591	0.1696
1	0.550	0.502	+0.092	0.3724
2	0.544	0.497	+0.189	0.3726
3	0.544	0.494	+0.255	0.3701
4	0.544	0.492	+0.291	0.3679
5	0.557	0.496	+0.384	0.3595
6	0.561	0.562	+0.387	0.3610
7	0.567	0.494	+0.435	0.3473
8	0.569	0.493	+0.437	0.3447
9	0.569	0.497	+0.457	0.3489
10	0.590	0.496	+0.490	0.3299
11	0.584	0.495	+0.494	0.3333
12	0.602	0.499	+0.533	0.3229
13	0.666	0.496	+0.587	0.2743
14	0.749	0.495	+0.682	0.2294
15	0.839	0.491	+0.787	0.1908
1	0.699	0.661	+0.189	0.3904
2	0.703	0.664	+0.285	0.3901
3	0.704	0.661	+0.386	0.3865
4	0.714	0.659	+0.487	0.3760
5	0.722	0.666	+0.539	0.3756
6	0.728	0.657	+0.566	0.36 5
7	0.733	0.655	+0.590	0.3590
8	0.734	0.659	+0.590	0.3610
9	0.751	0.658	+0.634	0.3485
10	0.759	0.657	+0.635	0.3421
11	0.802	0.657	+0.687	0.3144
12	0.894	0.655	+0.789	0.2662
13	0.970	0.655	+0.886	0.2351
14	1.050	0.657	+0.977	0.1799
1	0.840	0.821	+0.187	0.4102
2	0.837	0.820	+0.294	0.4112
3	0.837	0.815	+0.389	0.4080
4	0.842	0.815	+0.491	0.4035
5	0.852	0.815	+0.589	0.3977
6	0.869	0.812	+0.687 }	0.3818
7	0.880	0.819	+0.686 }	
8	0.888	0.817	+0.731	0.3744
9	0.903	0.819	+0.741	0.3665
10	0.948	0.823	+0.787	0.3433
11	0.908	0.819	+0.788	0.3629
12	0.931	0.818	+0.821	0.3492
13	1.002	0.814	+0.842	0.3103
14	1.032	0.809	+0.883	0.2944
15	1.115	0.815	+0.983	0.2653
16	1.199	0.820	+1.092	0.2398
17	1.274	0.819	+1.183	0.2188
1	0.978	0.982	+0.290	0.4279
2	0.978	0.979	+0.387	0.4252
3	0.983	0.982	+0.493	0.4244
4	0.987	0.980	+0.588	0.4199
5	0.997	0.977	+0.686	0.4124
6	1.012	0 976	+0.785	0.4023
7	1.031	0.982	+0.826	0.3947
8	1.041	0.978	+0.839	0.3870
9	1.044	0.974	+0.880	0.3828
10	1.082	0.982	+0.881	0.3672
11	1.067	0.979	+0.925	0.3732
12	1.144	0.978	+0.933	0.3358
13	1.193	0.976	+0.983	0.3144
14	1.236	0.971	+1.048	0.2959
15	1.262	0.982	+1.077	0.2913
16	1.339	0.979	+1.176	0.2655

Mr. Nelles.

(1)	(2)	(3)	(4)	(5)
1	1.120	1.148	+0.295	0.4422
2	1.118	1.148	+0.389	0.4432
3	1.119	1.146	+0.492	0.4408
4	1.125	1.148	+0.590	0.4385
5	1.123	1.141	+0.689	0.4356
6	1.144	1.149	+0.781	0.4286
7	1.158	1.141	+0.884	0.4159
8	1.173	1.143	+0.928	0.4093
9	1.236	1.141	+0.983	0.3769
10	1.189	1.140	+0.984	0.3992
11	1.190	1.136	+1.032	0.3516
12	1.209	1.135	+1.039	0.3865
13	1.240	1.147	+1.067	0.3787
14	1.337	1.146	+1.075	0.3377
15	1.410	1.148	+1.181	0.3125
1	1.250	1.300	+0.394	0.4528
2	1.250	1.296	+0.487	0.4507
3	1.254	1.297	+0.591	0.4496
4	1.256	1.301	+0.682	0.4501
5	1.263	1.297	+0.786	0.4440
6	1.274	1.296	+0.888	0.4380
7	1.299	1.297	+0.951	0.4261
8	1.325	1.296	+0.981	0.4128
9	1.379	1.296	+1.081	0.3892
10	1.443	1.296	+1.084	0.3636
11	1.453	1.300	+1.133	0.4011
12	1.466	1.305	+1.174	0.3844

Bazin's Series No. 201.

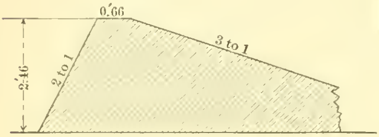


(1)	(2)	(3)	(4)	(5)
1	0.370	0.327	+0.141	0.3600
2	0.379	0.332	+0.178	0.3566
3	0.889	0.342	+0.231	0.3560
4	0.388	0.340	+0.234	0.3532
5	0.385	0.333	+0.277	0.3462
6	0.389	0.325	+0.328	0.3297
7	0.413	0.330	+0.365	0.3085
8	0.491	0.343	+0.462	0.2522
9	0.530	0.330	+0.509	0.2119
1	0.535	0.496	+0.180	0.3817
2	0.544	0.509	+0.232	0.3822
3	0.442	0.501	+0.277	0.3799
4	0.539	0.494	+0.326	0.3747
5	0.546	0.502	+0.364	0.3765
6	0.551	0.501	+0.418	0.3691
7	0.547	0.492	+0.421	0.3644
8	0.558	0.491	+0.461	0.3525
9	0.584	0.501	+0.512	0.3384
10	0.622	0.502	+0.565	0.3094
11	0.709	0.500	+0.657	0.2527
12	0.791	0.495	+0.754	0.2112
1	0.687	0.666	+0.230	0.4051
2	0.692	0.669	+0.274	0.4034
3	0.684	0.656	+0.320	0.3987
4	0.682	0.659	+0.365	0.4037
5	0.692	0.661	+0.461	0.3964
6	0.694	0.650	+0.516	0.3856
7	0.712	6.655	+0.562	0.3744
8	0.704	0.654	+0.565	0.3772
9	0.726	0.660	+0.613	0.3687
10	0.730	0.665	+0.614	0.3692
11	0.755	0.661	+0.661	0.3480
12	0.784	0.661	+0.700	0.3283
13	0.839	0.665	+0.748	0.3081
14	0.914	0.664	+0.849	0.2632
15	0.992	0.663	+0.940	0.2324
1	0.815	0.818	+0.273	0.4262
2	0.819	0.819	+0.327	0.4249
3	0.817	0.819	+0.367	0.4265
4	0.815	0.812	+0.469	0.4221
5	0.839	0.827	+0.561	0.4150
6	0.847	0.820	+0.656	0.4041
7	0.855	0.817	+0.705	0.3964
8	0.854	0.810	+0.711	0.3923
9	0.875	0.823	+0.747	0.3877
10	0.866	0.810	+0.747	0.3816
11	0.910	0.829	+0.787	0.3694
12	0.950	0.819	+0.842	0.3395
13	1.041	0.821	+0.934	0.2973
14	1.077	0.817	+0.984	0.2800
15	1.079	0.819	+1.026	0.2686
16	1.190	0.812	+1.126	0.2396
1	0.950	0.981	+0.325	0.4457
2	0.947	0.979	+0.371	0.4463
3	0.954	0.988	+0.460	0.4481
4	0.952	0.976	+0.507	0.4412
5	0.954	0.983	+0.559	0.4442
6	0.964	0.981	+0.663	0.4382
7	0.956	0.974	+0.746	0.4269
8	0.989	0.982	+0.792	0.4219
9	0.994	0.989	+0.794	
10	0.991	0.986	+0.791	
11	1.001	0.976	+0.839	0.4095
12	1.006	0.983	+0.848	0.4102
13	1.035	0.986	+0.884	0.3955
14	1.024	0.990	+0.888	0.4046
15	1.077	0.987	+0.931	0.3739
16	1.075	0.988	+0.933	
17	1.121	0.983	+0.983	0.3335
18	1.168	0.979	+1.030	0.3269
19	1.237	0.984	+1.114	0.3016
20	1.320	0.983	+1.219	0.2732
1	1.080	1.146	+0.467	0.4661
2	1.085	1.143	+0.561	0.4602
3	1.085	1.146	+0.658	0.4624
4	1.093	1.141	+0.755	0.4541
5	1.108	1.145	+0.837	0.4474
6	1.126	1.152	+0.885	0.4419
7	1.129	1.142	+0.936	0.4334
8	1.158	1.153	+0.987	0.4234
9	1.164	1.151	+0.992	0.4192
10	1.205	1.146	+1.029	0.3953
11	1.244	1.150	+1.071	0.3789
12	1.292	1.144	+1.118	0.3546
13	1.373	1.146	+1.222	0.3246
1	1.204	1.300	+0.567	0.4791
2	1.212	1.306	+0.655	0.4781
3	1.223	1.313	+0.739	0.4757
4	1.221	1.299	+0.841	0.4690
5	1.234	1.303	+0.939	0.4634
6	1.244	1.293	+0.987	0.4531
7	1.261	1.305	+1.035	0.4503
8	1.281	1.305	+1.077	0.4393
9	1.329	1.303	+1.120	0.4146
10	1.377	1.303	+1.170	0.3934
11	1.428	1.294	+1.222	0.3684
12	1.459	1.297	+1.264	0.3588
13	1.503	1.304	+1.314	0.3455
1	1.333	1.461	+0.657	0.4911
2	1.335	1.461	+0.742	0.4905

Mr. Nelles.

(1)	(2)	(3)	(4)	(5)
3	1.337	1.460	+0.842	0.4892
4	1.343	1.458	+0.933	0.4846
5	1.370	1.470	+1.029	0.4763
6	1.394	1.468	+1.119	0.4626
7	1.405	1·462	+1.171	0.4546
8	1.433	1.462	+1.212	0.4419
9	1.494	1.465	+1.263	0.4153
10	1.541	1.464	+1.313	0.3961

Bazin's Series No. 202.



(1)	(2)	(3)	(4)	(5)
1	0.380	0.330	+0.192	0.3523
2	0.383	0.328	+0.290	0.3442
3	0.408	0.339	+0.345	0.3280
4	0.427	0.330	+0.394	0.2945
5	0.471	0.336	+0.439	0.2602
6	0.513	0.329	+0.487	0.2227
1	0.548	0.494	+0.290	0.3674
2	0.552	0.493	+0.389	0.3614
3	0.570	0.493	+0.487	0.3447
4	0.610	0.503	+0.547	0.3211
5	0.646	0.504	+0.598	0.2952
6	0.684	0.506	+0.637	0.2725
7	0.931	0.500	+0.687	0.2422
1	0.703	0.656	+0.286	0.3838
2	0.704	0.657	+0.388	0.3833
3	0.707	0.655	+0.479	0.3792
4	0.736	0.665	+0.588	0.3644
5	0.756	0.656	+0.673	0.3448
6	0.832	0.666	+0.748	0.3048
7	0.861	0.661	+0.794	0.2865
8	0.923	0.665	+0.842	0.2609
9	0.946	0.663	+0.882	0.2498
1	0.855	0.824	—0.190	0.4024
2	0.853	0.820	+0.006	0.4018
3	0.853	0.823	+0.200	0.4040
4	0.854	0.822	+0.395	0.4017
5	0.858	0.824	+0.485	0.4006
6	0.870	0.827	+0.600	0.3943
7	0.884	0.823	+0.686	0.3828
8	0.910	0.825	+0.788	0.3679
9	0.978	0.820	+0.869	0.3268
10	1.088	0.824	+0.983	0.2808
11	1.176	0.832	+1.092	0.2529
1	1.001	0.987	+0.282	0.4176
2	1.002	0.986	+0.388	0.4159
3	1.002	0.984	+0.477	0.4151
4	1.012	0.993	+0.584	0.4141
5	1.010	0.983	+0.671	0.4086
6	1.026	0.989	+0.787	0.4035
7	1.055	0.991	+0.877	0.3877
8	1.059	0.991	+0.966	0.3693
9	1.109	0.988	+0.987	0.3590
10	1.198	0.991	+1.064	0.3203
11	1.283	0.992	+1.184	0.2897
12	1.375	0.993	+1.269	0.2617
1	1.152	1.150	+0.491	0.4256
2	1.151	1.150	+0.590	0.4271
3	1.151	1.151	+0.687	0.4249
4	1.171	1.161	+0.783	0.4224
5	1.182	1.151	+0.897	0.4107
6	1.201	1.154	+0.975	0.4028
7	1.247	1.152	+1.091	0.3795
8	1.322	1.158	+1.168	0.3504
9	1.454	1.157	+1.286	0.3035
1	1.295	1.317	+0.590	0.4392
2	1.295	1.314	+0.688	0.4379
3	1.302	1.314	+0.784	0.4357
4	1.311	1.313	+0.885	0.4310
5	1.326	1.320	+0.976	0.4255
6	1.342	1.314	+1.084	0.4156
7	1.385	1.323	+1.180	0.3998
8	1.443	1.316	+1.279	0.3738

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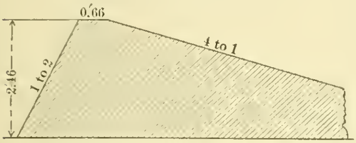
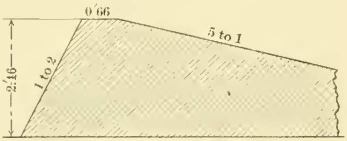


(1)	(2)	(3)	(4)	(5)
1	0.380	0.329	+0.186	0.3505
2	0.380	0.327	+0.284	0.3465
3	0.391	0.329	+0.332	0.3356
4	0.417	0.327	+0.385	0.3013
5	0.453	0.328	+0.431	0.2656
6	0.501	0.326	+0.484	0.2277
1	0.546	0.494	+0.291	0.3695
2	0.544	0.490	+0.388	0.3661
3	0.556	0.490	+0.485	0.3539
4	0.580	0.492	+0.533	0.3351
5	0.619	0.488	+0.584	0.2992
6	0.668	0.489	+0.632	0.2685
7	0.714	0.492	+0.684	0.2449
1	0.707	0.655	+0.289	0.3804
2	0.716	0.661	+0.380	0.3781
3	0.705	0.656	+0.391	0.3829
4	0.713	0.657	+0.491	0.3768
5	0.717	0.657	+0.588	0.3734
6	0.754	0.658	+0.684	0.3482
7	0.798	0.653	+0.730	0.3152
8	0.835	0.658	+0.780	0.2974
9	0.885	0.659	+0.831	0.2743
10	0.930	0.656	+0.886	0.2523
1	0.856	0.821	+0.293	0.3996
2	0.861	0.823	+0.393	0.3985
3	0.852	0.815	+0.490	0.3987
4	0.870	0.825	+0.591	0.3930
5	0.874	0.820	+0.683	0.3870
6	0.899	0.825	+0.785	0.3746
7	0.949	0 819	+0.881	0.3416
8	1.049	0.820	+0.951	0.2969
9	1.147	0.819	+1.078	0.2568
1	1.016	0.988	+0.482	0.4092
2	1.015	0.984	+0.592	0.4075
3	1.019	0.983	+0.680	0.4043
4	1.026	0.983	+0.780	0.4001
5	1.045	0.982	+0.878	0.3886
6	1.085	0.985	+0.983	0.3690
7	1.166	0.984	+1.072	0.3306
8	1.284	0.985	+1.182	0.2864
9	1.365	0.885	+1.274	0.2612
1	1.170	1.151	+0.578	0.4170
2	1.158	1.141	+0.689	0.4173
3	1.179	1.154	+0.775	0.4137
4	1.180	1.150	+0.881	0.4108
5	1.196	1.150	+0.976	0.4030
6	1.222	1.147	+1.072	0.3888
7	1.288	1.150	+1.176	0.3603
8	1.330	1.150	+1.273	0.3428
1	1.321	1.315	+0.682	0.4256
2	1.322	1.313	+0.784	0.4242
3	1.326	1.313	+0.879	0.4223
4	1.337	1.316	+0.980	0.4182
5	1.348	1.316	+1.068	0.4134
6	1.382	1.318	+1.181	0.3990
7	1.422	1.314	+1.278	0.3806

Bazin's Series No. 204.



(1)	(2)	(3)	(4)	(5)
1	0.384	0.330	+0.186	0.3459
2	0.383	0.329	+0.294	0.3457
3	0.390	0.330	+0.338	0.3380
4	0.430	0.329	+0.389	0.2897
5	0.450	0.330	+0.435	0·2718
6	0.510	0.328	+0.493	0.2237
1	0.545	0.487	+0.287	0.3620
2	0.556	0.495	+0.394	0.3609
3	0.556	0.489	+0.497	0.3537
4	0.582	0.490	+0.535	0.3310
5	0.588	0.496	+0.538	0.3326
6	0.622	0.486	+0.589	0.2966
7	0.658	0.492	+0.632	0.2764
8	0.720	0.486	+0.681	0.2380
1	0.714	0.659	+0.491	0.3774
2	0.723	0.657	+0.487	0.3693
3	0.765	0.658	+0.671	0.3410
4	0.786	0.662	+0.734	0.3288
5	0.837	0.658	+0.775	0.2992
6	0.880	0.663	+0.830	0.2785
7	0.929	0.676	+0.890	0.2642
1	0.871	0.827	+0.297	0.3930
2	0.870	0.822	+0.383	0.3903
3	0.883	0.833	+0.492	0.3901
4	0.875	0.822	+0.579	0.3873
5	0.894	0.836	+0.642	0.3848
6	0.900	0.822	+0.779	0.3711
7	0.962	0.832	+0.891	0.3422
8	1.041	0.822	+0.969	0.2988
9	1.145	0.832	+1.086	0.2638
1	1.026	0.986	+0.586	0.4022
2	1.025	0.984	+0.688	0.4012
3	1.025	0.978	+0.786	0.3981
4	1.049	0.982	+0.885	0.3866
5	1.070	0.978	+0.978	0.3731
6	1.158	0.983	+1.077	0.3334
7	1.260	0.983	+1.172	0.2940
8	1.349	0.882	+1.273	0.2647
1	1.175	1.148	+0.591	0.4129
2	1.183	1.147	+0.686	0.4080
3	1.182	1.150	+0.784	0.4101
4	1.188	1.144	+0.879	0.4041
5	1.211	1.153	+0.986	0.3971
6	1.227	1.150	+1.072	0.3880
7	1.276	1.146	+1.180	0.3632
8	1.380	1.148	+1.270	0.3243
1	1.329	1.312	+0.689	0.4190
2	1.338	1.313	+0.782	0.4163
3	1.337	1.312	+0.887	0.4166
4	1.347	1.312	+0.976	0.4119
5	1.353	1.305	+1.078	0.4065
6	1.380	1.313	+1.175	0.3975
7	1.421	1.310	+1.276	0.3791

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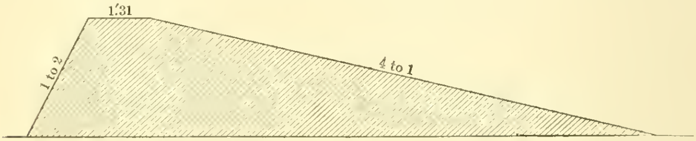
Bazin's Experiments.—Series No. 205.

Nappe wetted underneath, with water retained in pool below weir. Description of weir under observation: Height, 0.75 m. = 2.46 ft. Length, 2.0 m. = 6.56 ft. Crest, 0.40 m. = 1.31 ft. wide. Both faces inclined.

Bazin's Series No. 205.



(1)	(2)	(3)	(4)	(5)
1	0.385	0.330	+0.305	0.3438
2	0.393	0.332	+0.354	0.3368
3	0.418	0.328	+0.393	0.3010
4	0.461	0.327	+0.441	0.2501
5	0.512	0.329	+0.491	0.2230
1	0.561	0.491	+0.386	0.3505
2	0.570	0.493	+0.491	0.3444
3	0.593	0.493	+0.538	0.3240
4	0.622	0.496	+0.593	0.3045
5	0.675	0.493	+0.642	0.2662
6	0.709	0.495	+0.689	0.2503
1	0.749	0.655	+0.591	0.3182
2	0.749	0.660	+0.639	0.3531
3	0.768	0.652	+0.691	0.3335
4	0.794	0.658	+0.741	0.3220
5	0.834	0.657	+0.786	0.2980
6	0.877	0.660	+0.839	0.2789
7	0.922	0.660	+0.887	0.2568
1	0.900	0.816	+0.394	0.3681
2	0.900	0.818	+0.494	0.3695
3	0.904	0.816	+0.590	0.3649
4	0.908	0.822	+0.688	0.3669

(1)	(2)	(3)	(4)	(5)
5	0.922	0.815	+0.788	0.3544
6	0.956	0.819	+0.884	0.3375
7	1.029	0.814	+0.986	0.2997
8	1.133	0.819	+1.084	0.2619
9	1.226	0.814	+1.183	0.2309
1	1.075	0.986	+0.694	0.3752
2	1.075	0.983	+0.782	0.3733
3	1.091	0.988	+0.886	0.3681
4	1.106	0.984	+0.975	0.3581
5	1.159	0.987	+1.081	0.3355
6	1.247	0.885	+1.178	0.2997
7	1.345	0.887	+1.286	0.2684
1	1.238	1.147	+0.886	0.3813
2	1.251	1.151	+0.981	0.3767
3	1.258	1.143	+1.081	0.3697
4	1.292	1.146	+1.179	0.3568
5	1.360	1.144	+1.277	0.3292
1	1.399	1.311	+0.985	0.3891
2	1.413	1.311	+1.088	0.3830
3	1.426	1.312	+1.182	0.3783
4	1.449	1.312	+1.279	0.3694

"We have already shown, in discussing the similar experiments on beam weirs, that the size of the crest completely modifies the effect of the retained water. Thus, for weirs in thin partition, the effect of the retained water is manifest before it reaches the level of the crest, while for weirs with wide crest, the effect is not noticeable until the level of the retained water is above the crest. In order to show the results of the preceding experiments in a comprehensive manner, we have prepared the following tables, which show for the same discharge and for varying elevations of the retained water, the corresponding heads on the weirs under experiment.

"Notwithstanding some anomalies, the tables show that the influence of the retained water is hardly sensible so long as its height above the crest h_1 is less than one-half the head h. When we consider Series 205, in which the crest is 0.40 m. (1.31 ft.) wide, it is seen that the influence of the retained water is not appreciable until it attains a height of two-thirds of the head."

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TABLE SHOWING THE HEADS CORRESPONDING TO THE SAME DISCHARGE OVER WEIRS WITH SHARP CRESTS AND SLOPING FACES, FOR VARIOUS ELEVATIONS OF THE SURFACE OF THE WATER RETAINED BELOW WEIR.

Head on standard weir of comparison. (H_1)	Head when the discharge is not affected by the retained water.	HEAD, IN FEET, ON THE WEIRS UNDER CONSIDERATION. (h.)								
		Height of the water surface below the weirs, below or above the level of the crest. (h_1)								
		−0.198	0	+0.198	+0.394	+0.591	+0.787	+0.984	+1.181	
0.492	0.456	0.459	0.472	0.515	0.591	0.591	0.591	0.591	0.591	*Series No. 195.* Upper face vertical; lower face 1 to 1.
0.656	0.601	0.611	0.620	0.653	0.722	0.810	0.810	0.810	0.810	
0.820	0.748	0.752	0.765	0.807	0.869	0.942	1.024	1.024	1.024	
0.984	0.893	0.899	0.909	0.939	1.000	1.080	1.158	1.237	1.237	
1.148	1.040	1.043	1.060	1.096	1.151	1.217	1.286	1.352	1.352	
1.312	1.184	1.194	1.214	1.254	1.302	1.355	1.408	1.470	1.470	
0.492	0.485	0.485	0.489	0.512	0.575	0.575	0.575	0.575	0.575	*Series No. 196.* Upper face vertical; lower face 2 to 1.
0.656	0.643	0.643	0.646	0.666	0.702	0.797	0.797	0.797	0.797	
0.820	0.797	0.797	0.804	0.813	0.843	0.919	1.033	1.033	1.033	
0.984	0.948	0.978	0.978	0.964	0.987	1.037	1.136	1.250	1.250	
1.148	1.109	1.109	1.109	1.116	1.136	1.168	1.230	1.348	1.348	
1.312	1.267	1.267	1.267	1.267	1.212	1.312	1.365	1.437	1.437	
0.492	0.528	0.528	0.528	0.528	0.551	0.669	0.669	0.669	0.669	*Series No. 197.* Upper face vertical; lower face 5 to 1.
0.656	0.696	0.696	0.696	0.696	0.699	0.745	0.889	0.889	0.889	
0.820	0.863	0.863	0.863	0.863	0.863	0.886	0.961	1.076	1.076	
0.984	1.030	1.030	1.030	1.030	1.030	1.033	1.073	1.174	1.325	
1.148	1.201	1.201	1.201	1.201	1.201	1.201	1.217	1.279	1.388	
1.312	1.368	1.368	1.368	1.368	1.368	1.368	1.368	1.404	1.483	

TABLE SHOWING THE HEADS CORRESPONDING TO THE SAME DISCHARGE OVER WEIRS WITH CRESTS 0.20 M. = 0.66 FT. WIDE, AND SLOPING FACES, FOR VARIOUS ELEVATIONS OF THE SURFACE OF THE RETAINED WATER.

0.492	0.528	....	....	0.552	0.522	0.653	0.653	0.653	0.653	*Series No. 198.* Upper face inclined, 1 to 2; lower face inclined, 1 to 1.
0.656	0.682	....	....	0.686	0.694	0.745	0.889	0.889	0.889	
0.820	0.817	....	....	0.817	0.830	0.863	0.964	1.103	1.103	
0.984	0.954	....	....	0.954	0.961	0.981	1.053	1.188	1.188	
1.148	1.090	....	....	1.090	1.145	1.106	1.155	1.273	1.273	
1.312	1.217	....	....	1.217	1.267	1.230	1.267	1.371	1.371	
0.492	0.538	....	....	0.542	0.555	0.646	0.843	0.843	0.843	*Series No. 200.* Upper face inclined, 1 to 2; lower face inclined, 2 to 1.
0.656	0.686	....	....	0.689	0.696	0.732	0.889	1.063	1.063	
0.820	0.833	....	....	0.837	0.840	0.856	0.939	1.116	1.286	
0.984	0.974	....	....	0.974	0.981	0.987	1.000	1.178	1.361	
1.148	1.113	....	....	1.113	1.119	1.123	1.148	1.217	1.418	
1.312	1.257	....	....	1.257	1.260	1.267	1.276	1.315	1.457	
0.492	0.542	....	....	0.545	0.551	0.623	0.623	0.623	0.623	*Series No. 202.* Upper face inclined, 1 to 2; lower face inclined. 3 to 1.
0.656	0.699	....	....	0.702	0.706	0.732	0.850	0.850	0.850	
0.820	0.850	....	....	0.850	0.856	0.860	0.912	1.080	1.080	
0.984	1.000	....	....	1.000	1.000	1.004	1.024	1.109	1.276	
1.148	1.145	....	....	1.145	1.145	1.148	1.158	1.197	1.322	
1.312	1.289	....	....	1.289	1.289	1.289	1.295	1.319	1.375	
0.492	0.542	....	....	0.542	0.548	0.623	0.623	0.623	0.623	*Series No. 203.* Upper face inclined, 1 to 2; lower face inclined, 4 to 1.
0.656	0.706	....	....	0.706	0.709	0.722	0.843	0.843	0.843	
0.820	0.856	....	....	0.856	0.856	0.863	0.899	1.043	1.043	
0.984	1.010	....	....	1.010	1.010	1.014	1.027	1.090	1.276	
1.148	1.161	....	....	1.161	1.161	1.164	1.171	1.197	1.282	
1.312	1.312	....	....	1.312	1.312	1.312	1.319	1.332	1.375	
0.492	0.548	....	....	0.548	0.551	0.630	0.630	0.630	0.630	*Series No. 204.* Upper face inclined, 1 to 2; lower face inclined, 5 to 1.
0.656	0.706	....	....	0.706	0.725	0.833	0.833	0.833	0.833	
0.820	0.863	....	....	0.863	0.866	0.873	0.906	1.037	1.037	
0.984	1.024	....	....	1.024	1.034	1.030	1.090	1.263	1.263	
1.148	1.178	....	....	1.178	1.178	1.178	1.181	1.204	1.289	
1.312	1.332	....	....	1.332	1.332	1.332	1.335	1.345	1.385	

Mr. Nelles. From a consideration of the foregoing and other experiments on the flow over submerged weirs, the writer is impressed with the idea that the usual laboratory methods are to some extent defective and misleading, in that the conditions are artificial, and differ, except for the rare case of a flow into a reservoir, from those met in actual practice. In the laboratory experiments, the level of the backwater is regulated by impeding the flow away from the weir, and decreasing the velocity of departure; whereas, in practice, in the usual case of a dam in a flowing stream, the conditions are natural, and the height of the water surface below and the fall over the dam depend upon the quantity of water passing. It is not unlikely that some of the discrepancies hereafter noted are due to this cause.

The most common use to which engineers apply the theory and formulas for the flow over submerged dams is in connection with the slack-water improvement of rivers, for the determination of the effect of the dams in raising the water surface above them, and for the determination of the fall at the dams, in order to fix the height of the lock walls and the stage at which navigation over the dam itself will become possible.

A number of formulas have been proposed for this purpose. That which is most generally used is based on the theory that the flow above the level of the lower pool is similar to a free discharge into air, and that the usual weir formulas for such discharge are applicable for its determination. The flow between the level of the lower pool and the crest of the dam is considered similar to that from a submerged orifice, and determined by the recognized formulas for such flow. By combining the common expressions for the two forms of flow, the following general formula (which should be corrected for the effect of the velocity of approach), is obtained:

$$Q = C'L \sqrt{2\,g\,z}\,(h_1 + \tfrac{2}{3}\,z) \ldots\ldots\ldots\ldots\ldots\ldots (b)$$

in which

Q = discharge, in cubic feet per second;
C' = a coefficient;
L = crest length of dam, in feet;
z = fall at dam;
h_1 = height of lower pool above crest of dam.

Several methods of taking into account the effect of the velocity of approach have been advanced. The simplest of these, although not the most accurate, which will be used in the present discussion, consists of increasing the head to which the velocity of flow is due, by the head to which the mean velocity of approach is due, making the quantity under the radical in Equation (*b*)

$$\sqrt{2\,g\,\left(z + \frac{v^2}{2\,g}\right)}$$

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The theory of Equation (*b*) makes the coefficient C' equal to 1.5 times the coefficient m of the free portion of the discharge.

Francis, from small-scale experiments on sharp-crested vertical weirs, makes this ratio 1.38. D'Aubisson gives it at 1.43. Weisbach accepts the value assigned by theory.

The results of a large number of Bazin's experiments, Series Nos. 200 and 201, have been applied to Formula (*b*) by the writer, giving values for the coefficient C' of from 0.71 to 1.20, and of the ratio $\frac{C'}{m}$ of from 1.54 to 2.40. These results, which included the effect of the velocity of approach, showed, without apparent reason, such a wide variation that no satisfactory conclusions could be drawn from the investigation.

From a careful study and manipulation of the gauge records at the locks and dams on the Kentucky River, covering 65 days in February, March and April, 1886,* it has been possible to deduce approximate values for the ratio $\frac{C'}{m}$ for these dams. The dams consist of rock-filled cribs, with planked up-stream faces sloping at 3 to 1, and with vertical steps below the crest. The height of the dams is about 20 ft.

The deductions were made as follows: From the gauge records, periods of nearly uniform flow and conditions were selected, during which at least one of the dams was submerged, while one or more of the adjacent dams was not. Then, from the mean head for the selected period at the dams not submerged, a probable mean discharge was obtained by the usual weir formula. This discharge was assumed to be that at the dam under submerged flow, and, with the other mean conditions shown by the records to exist at the submerged dam, was substituted in Formula (*b*), which then gave the corresponding value for the coefficient C'. By comparing the value thus obtained with the value of the coefficient m, used in determining the free discharge, the ratio $\frac{C'}{m}$ was obtained.

In this way, three separate determinations were made. The first, covering four days, when the water was falling slowly, Dams Nos. 4 and 5 being under free flow, and Dam No. 3 submerged, giving $\frac{C'}{m} =$ 1.50.

The second, covering three days, while the water was falling slowly, Dams Nos. 3 and 4 being under free flow, and Dam No. 2 submerged, giving $\frac{C'}{m} = 1.53$.

The third, covering five days, during which the river rose and fell

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* Annual Report, Chief of Engineers, U. S. A., 1887, pp. 1318 and 1319.

Mr. Nelles. slowly, Dams Nos. 2 and 3 being under free flow, and Dam No. 1 submerged, giving $\frac{C'}{m} = 1.46$. The mean value of the ratio $\frac{C'}{m}$ for the 11 days being 1.49.

The depths on the crest ranged from 4 to 7.5 ft., with a mean of 5.3 ft.

Another formula, used frequently for the same purposes as Formula (*b*), is known as the Chanoine and Mary Formula.

$$Q = M L h, \sqrt{2 g z} \ldots\ldots\ldots\ldots\ldots\ldots (c)$$

This is of the same form as the usual submerged orifice or sluice formulas, and, while it is applicable to conditions identical with those for which the coefficient M is known, it cannot be safely used otherwise. This is demonstrated by Mr. Edward Sawyer in an article,* in which he illustrates his assertion by assuming a case wherein the level of the upper pool remains constant, while that of the lower pool is lowered. For this case, the formula gives a decreasing value for Q, whereas the contrary would actually result.

The formula given by Chanoine and DeLagrene, in their memoir on the dams of the Upper Seine, is very generally used by French engineers. This formula is based on the theory that for a given discharge, the effect produced by a submerged dam, or other impediment to flow, in raising the level of the water surface above it, is represented by the difference between the heads to which the mean velocity at the dam site is due, before and after the execution of the works, multiplied by a coefficient to which is usually given a value of 1.5. This theory is expressed by the following formula:

$$z = K \left(\frac{V_1^2 - V^2}{2 g} \right) \ldots\ldots\ldots\ldots\ldots\ldots (d)$$

The writer has tested this formula by the substitution of the data taken from Bazin's Series No. 200. The resulting values for the coefficient K ranged from 0.25 to 1.45, and were so erratic that the selection of even a probable value was found practically impossible. A further test was made by using the results of the actual observations on the flow over the twelve dams on the Upper Seine.† In this way K was found to vary, without apparent reason, independent of z, from 0.30 to 2.50.

The most elaborate published account of the flow over submerged dams of practical dimensions and form is found in a paper by Mr. R. H. Rhind.‡ This paper describes and discusses in considerable detail observations made at a number of large masonry dams in India. Most of the dams have flat crests, with paved slopes. The exact dimensions in these particulars are not given. The discharge was calculated by

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* *Van Nostrand's Magazine*, Vol. xxxiv, p. 176.

† Annales des Ponts et Chaussées, 1868.

‡ *Proceedings* of the Institute of Civil Engineers, for 1886.

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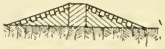
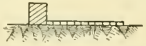
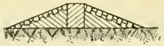
TABLE No. 22.—DIMENSIONS OF AND OBSERVED CONDITIONS OF FLOW AT CERTAIN LARGE MASONRY DAMS IN INDIA, WITH CORRESPONDING COEFFICIENTS OF DISCHARGE.*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Name of river.	Name of weir.	MAKE UP OF WEIR.		DEPTH OF CREST BELOW WATER SURFACE IN		Observed fall over weir, feet.	Mean surface velocity of approach, in feet per second.	Corresponding velocity head. feet.	Calculated discharge, in cubic feet per second.	Height of main body of weir, feet.	COEFFICIENTS OF DISCHARGE IN THE VARIOUS SUBMERGED-FLOW FORMULAS.					Approximate section of weir.
		Description of parts.	Length of parts, in feet.	Upper pool, feet.	Lower pool, feet.						Formula *e*, observed head corrected for velocity of approach.	Formula *b*, observed heads		Formula *a*, observed heads.		
												Corrected for velocity of approach.	Not corrected for velocity of approach.	Corrected for velocity of approach.	Not corrected for velocity of approach.	
			L	h	h_1	$h-h_1=z$	v	$\frac{v^2}{2g}$	Q	p						
Brahmini	Pattia....	Main body.....	665	19.21	18.35	0.86	7.84	0.96	114 000	...	0.881	0.806	1.172	0.241	0.248	
		First step......	60	8.21	7.35											
		Second step....	9	2.21	1.35											
Byturnee	Byturnee	Sluices.........	100	18.10	15.29	2.81			Total 260 000	7.9	0.953	0.940	1.125	0.491	0.502	
		Piers...........	14	7.68	4.87											
		Main body.....	912	10.84	8.03											
		Total overfall.	1 026	......	......	....	8.51	1.13								
	Burrah...	Sluices.........	100	18.60	15.20	3.40			For main body alone 212 400	7.9	0.979	0.970	1.148	0.511	0.534	
		Piers...........	14	8.18	4.78											
		Main body.....	412	11.34	7.94											
		Total overfall.	526													
Brahmini	Brahmini	Sluices.........	389	18.02	17.55	0.47										
		Piers...........	140	8.02	7.55		6.99	0.76	....	7.5						
		Main body.....	3 471	10.52	10.05	....	......	....	260 000		0.878	0.790	1.250	0.266	0.257	
		Total overfall.	4 000	......	......	....	......	....	307 500		0.876	0.786	1.275	0.245	0.252	
Manha-nuddy	Kajooree	Sluices.........	90	30.675	30.15	0.525										Same as above.
		Breaches......	324	25.615	25.09		11.62	2.10	....	10.65	....	......	......	......	......	
		Main body.....	3 433	20.115	19.59	....	......	....	680 000		0.893	0.764	1.710	0.261	0.274	
		Total overfall.	3 847	......	......	....	......	....	787 000		0.891	0.763	1.705	0.355	0.267	
Manha-nuddy	Manha-nuddy	Shore sluices..	190	17.45	15.45	2.00										Same as above.
		Center sluices.	460	17.20	15.20		7.74	0.93	....	6.00	....	......	......	......	......	
		Main body.....	5 696	11.45	9.45	....	......	....	488 000		0.595	0.561	0.679	0.265	0.276	
		Total overfall.	6 346	......	......	....	......	....	609 000		0.633	0.597	0.722	0.274	0.284	
Manha-nuddy	Beropa..	Sluices.........	255	13.30	12.10	1.20										Same as above.
		Piers...........	118	4.30	3.10		6.65	0.68	....	5.00	....	......	......	......	......	
		Main body.....	1 607	8.30	7.10	....	......	....	82 800		0.594	0.570	0.715	0.244	0.255	
		Total overfall.	1 980	......	......	....	......	....	112 700		0.648	0.677	0.846	0.260	0.271	

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* Compiled and calculated from Paper No. 2171. *Minutes of Proceedings*, Institution of Civil Engineers. Vol. LXXXV, p. 307.

Mr. Nelles. the Humphrey and Abbott Formula, and covers an unusually wide range. Table No. 22, which has been prepared from Mr. Rhind's paper, shows the shape and known dimensions of the dams, the calculated discharge, the observed conditions and deduced coefficients.

In deducing his coefficients, Mr. Rhind used the formula

$$Q = C_1 \, L \sqrt{2\,g} \left[h_1 \sqrt{z + 0.01\, v^2} + \frac{2}{3} z \sqrt{z + 0.035\, v^2} \right] \ldots\ldots\ldots\ldots (e)$$

in which v represents the mean surface velocity of approach. This formula may be reduced to the same form as (b) by neglecting the correction for the velocity of approach.

In addition to the information and results taken from Mr. Rhind's paper, the writer has calculated from the same data and shown in Columns 13 to 16 of Table No. 22, the coefficients of discharge for Formulas (a) and (b); first, considering the effect of the velocity of approach, by increasing the observed head an amount equal to $\frac{v^2}{2\,g}$; second, not considering the effect of the velocity of approach, and using the observed heads in the formulas.

The results in Table No. 22 indicate clearly the necessity for specially considering the effect of the velocity of approach in connection with Formula (b), and show a marked uniformity in the value of the coefficient m in Formula (a), notwithstanding a very wide and inexplicable variation in the values of the coefficient C'.

Van Nostrand's Magazine, Vol. xxxii, page 473, gives the following details of certain observations on the Bazacle Dam in the Garonne River at Toulouse:

$h = 6$ m.;
$h_1 = 5$ m.;
$h - h_1 = z = 1$ m.;
$L = 283$ m.;
$Q = 6500$ cu. m. per second.

Substituting these quantities in Formula (b), we find $C' = 0.915$. Correcting z for a mean velocity of approach of 3.4 m. per second, we find $C' = 0.724$ In the same way, by means of Formula (a), we find $m = 0.353$ and 0.336.

This discussion has been carried to a considerable length in order to illustrate the present state of our practical knowledge on the general question of flow of water over dams, and, aside from the Bazin experiments, much of the matter presented has very little intrinsic value except for this purpose. It is hoped, however, that the illustrations given may attract the attention of skilled investigators to this field, and thus indirectly lead to a more satisfactory solution of the problem of submerged flow.

Some valuable and interesting features of the Bazin experiments have not been noticed by Mr. Rafter; principal among these are the distribution of pressure and velocity in the nappe. Concerning these features, Bazin says in his summary: Mr. Nelles.

"The pressure under the nappe has been measured in nearly every experiment. For a certain number of them we have determined the interior distribution of both the pressure and velocity. This distributions presents a theoretic interest, but cannot, like the pressure under the nappe, be put to practical use. For a weir of given form, the coefficient *m* depends principally on two elements, the contraction at the sill and the pressure under the nappe. This pressure is so clearly related to the discharge that we can, by proper observations, deduce from it the variation in the discharge, with a precision not to be obtained by the direct measure of the heads.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

PAPERS AND DISCUSSIONS.

Note.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

RECENT STADIA TOPOGRAPHIC SURVEYS: NOTES RELATING TO METHODS AND COST.

Discussion.*

By G. L. Christian, Assoc. M. Am. Soc. C. E.

Mr. Christian. G. L. Christian, Assoc. M. Am. Soc. C. E. (by letter).—The writer fully agrees with Mr. Allen that the cost of topographical surveys depends upon the character of the ground, the extent of the survey, the scale of the map, transportation facilities, board, etc. The season of the year is also a very important factor.

For instance, in the Middle Atlantic States, the work can generally be performed to much greater advantage early in the spring or late in the fall, especially if the district is heavily wooded.

In 1896 the writer made a survey of a 57-acre tract of land in Westchester County, N. Y., which the owners wished to subdivide. Most of the work was done during the month of July, and the weather was exceedingly hot and sultry.

Three-quarters of the tract was woodland, with much thick underbrush and heavy foliage. The land was much broken, and varied from a rise of 2 ft. in 100 to a rise of 40 ft. in 100, and had a total rise of 150 ft.

The transit lines (12 750 ft.) were first run so as to cover what seemed to be controlling points, such as along the tops of ridges, at the foot of hills, etc., stakes being set every 50 ft.; after which levels were carefully run over the whole line with a wye level, elevations being taken at each stake, and at intermediate points if necessary.

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* Continued from May, 1900, *Proceedings*. See March, 1900, *Proceedings*, for paper by William B. Landreth, M. Am. Soc. C. E., on this subject.

Mr. Christian.

From these lines and levels the 5-ft. contours were located on the ground, at right angles to the transit lines, with a Gurley hand level, an ordinary level rod and a steel tape.

The actual working time of the field party each day was from 9 A. M. to 5 P. M., with one hour for lunch. The work was 2 miles from the office, and transportation, consisting of a horse and wagon, was furnished each way.

The net cost of the field work, transportation, stakes, and mapping was $1.47 per acre, divided as follows:

Field work including transportation:		
Running transit lines	$0.40	
" wye levels	0.19	
Five-ft. contours, with hand level	0.53	
Total		$1.12
Stakes		0.07
Mapping:		
Plotting transit lines	$0.13	
" contour "	0.15	
Total mapping,		0.28
Grand total		$1.47

The map was plotted on a scale of 100 ft. to 1 in.

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THE PRACTICAL COLUMN UNDER CENTRAL OR ECCENTRIC LOADS.

Discussion.*

By Messrs. C. T. PURDY, WILLIAM CAIN and J. L. POWER O'HANLY.

Mr. Purdy. C. T. PURDY, M. Am. Soc. C. E.—This is an extremely practical subject for engineers who have many columns to dimension or design. In the Astoria Hotel there are about 3 600 separate columns, each of which had to be especially considered. Ten minutes given to each would require 600 hours for all of them. In the speaker's practice every column is analyzed; if there are eccentric loads the exact effects must be determined, and it is therefore important that the methods should be such as will secure the greatest amount of work in the least possible time.

Very few who write regarding column designing realize or appreciate the importance of eccentricity of loading. The speaker does not refer to bridge designing so much as to building work. Most of the columns in buildings are short, and therefore the element of eccentric loading becomes the more important one. The effect of the direct load in such columns is mostly a crushing strain, while the element of bending is of least importance. The effect of eccentricity is rarely lacking, for an even loading is exceptional. From the practical point of view, therefore, the speaker believes that the author's first statement is the most notable one in the paper.

There is great need for a thorough series of experiments on eccentrically loaded columns, but the task is too great to be undertaken by a private engineer. So far as the speaker knows, only two practical tests of eccentrically loaded columns have been made. Mr. Purdy.

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* Continued from May, 1900, *Proceedings*. See March, 1900, *Proceedings*, for paper by J. M. Moncrieff, M. Am. Soc. C. E., on this subject.

William Cain, M. Am. Soc. C. E. (by letter).—This is a valuable paper, not only for a very clear presentation of the theory affecting the practical column, but for the numerous diagrams comparing the theory, supposed to apply to crippling loads approximately, with the results of 1 789 tests of columns by various experimenters. Mr. Cain.

Assuming the neutral line of the column under eccentric loading to be a parabola, the author's equations (5), (7) and (8), follow logically. The writer has called attention* to the propriety of using the parabola approximately, for the neutral line, by comparing results with the exact formula and finding them identical when $\frac{l}{r}$ was small. The agreement is still more plainly seen when the author's equation

$$\triangle = \frac{P\,l^2\,e}{8\,E\,I - \frac{5}{6}\,P\,l^2} \qquad (2)$$

for the deflection at the center of the column pivoted at the ends, from the primitive axis, is compared with the exact result for a prismatic homogeneous column,†

$$\triangle = e\left[\sec\left(\frac{1}{2}\,\frac{l}{r}\sqrt{\frac{P}{A\,E}}\right) - 1\right]$$

Putting $\theta = \frac{1}{2}\,\frac{l}{r}\sqrt{\frac{P}{A\,E}}$, the development of sec θ for those values of $\frac{l}{r}$ that give a converging series, is found by the differential calculus to be

$$\text{Sec}\ \theta = 1 + \frac{\theta^2}{2} + \frac{5}{24}\,\theta^4 + \frac{61}{720}\,\theta^6 + \ldots\ldots$$

On neglecting θ^6 and higher powers of θ, the last formula gives approximately,

$$\triangle = \frac{e}{8}\,\frac{l^2}{r^2}\,\frac{P}{A\,E}\left[1 + \frac{5}{48}\,\frac{l^2}{r^2}\,\frac{P}{A\,E}\right]$$

which is sensibly correct when θ is a comparatively small fraction, and incorrect otherwise.

But this is exactly equal to Equation (2), if the numerator is divided by the denominator in the right member and the division carried out to two terms.

Hence the assumption that the neutral line is approximately a parabola for small values of $\frac{l}{r}$ is again proved. The result is a closer

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* "Theory of the Ideal Column," *Transactions*, Am. Soc. C. E., Vol. xxxix, p. 120.

† See Mr. Marston's Formula (1); *Transactions*, Am. Soc. C. E., Vol. xxxix, p. 113.

Mr. Cain. approximation, likewise, than that given in "Theory of the Ideal Column" where the writer neglected terms containing θ^4 and higher powers of θ.

Of course, the approximate development for $\triangle$ could not be used for most of the values of $\frac{l}{r}$ given on the author's diagrams, and it cannot be utilized, therefore, in deducing the equivalents of (7) and (8); in fact, there would be no gain in doing so, as the author's formulas are briefer than the results corresponding.

The most compact formula is the exact one given by Ernst F. Jonson, Assoc. M. Am. Soc. C. E.,* and which, adopting the author's notation, is.

$$\frac{l}{r} = \sqrt{\frac{E}{f_d}} \cos^{-1} \left(\frac{c\,e}{r^2} \frac{f_d}{f_b} \right)$$

where $f_b = (F_c - f_d)$ for the extreme fiber on the concave side and $f_b = (-F_t + f_d)$ for the extreme fiber on the convex side, F_t being + when compressive, — when tensile (page 336).

Recurring now to "the application of the formulas in practice" (page 400), there is room for difference of opinion as to basing the factor of safety on the lower-limit curves of the diagrams, especially where the lower-limit curves pass below all the plotted positions as given by experiment.

If very small factors of safety are used, then, undoubtedly, the lower-limit curves should give the basis for the formulas to use in practice, or disaster might follow on increasing the loads, as the column in question might have a crippling strength near that given by the lower-limit curve. Thus, if the factor of safety was 2 and the loads were eventually doubled (as has happened on a number of railways in this country in the past), the column would certainly be regarded as dangerous if the factor 2 was based on the average curve passing somewhat centrally through the points on the diagram given by experiment.

But if the factor is 4 or 5, it seems safe to take the average curve, even if the loads are to be doubled in twenty or thirty years. Some of the columns will thus have factors of safety above that given and others below; so it would seem that the greatest economy should be secured by basing the safe curve upon the average curve.

If there is any merit in this contention, then the objection is more marked when for flat-ended columns "the curve indicating the load at which tensile stress commences," falls far below the results for experiments, as in some of the diagrams. In fact, failure does not begin for such a load for any given column. The case is similar in one respect

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* *Proceedings*, Am. Soc. C. E., May, 1900, p. 601.

Mr. Cain.

to the voussoir arch without mortar joints, when the line of the centers of pressure falls outside the middle third. No tension is exerted on a joint where this occurs, but the compressive stresses are distributed according to a uniformly increasing law, and the material may be strong enough to withstand the maximum stress induced. Similarly, in the column, where the resultant force is not too near the edges of the end sections, the maximum stresses in the extreme fibers may not be too great for strength or stability. Some allowance, however, should be made here for such cases, and the results of experiments should be the main guide.

Mr. O'Hanly.

J. L. Power O'Hanly, M. Am. Soc. C. E. (by letter).—This is an interesting paper on a most important subject. The demonstration is simply faultless. The theory, now for the first time propounded, as far as the writer is aware, only requires a multiplication of tests to bring the unassignable elements of the problem into closer harmony with the results of experiment, in order to subject them to the leash of induction. The subjoined remarks will be confined to this phase of the inquiry. The writer has adopted the author's notation and data when not otherwise specified.

1. "*Test No. 5 of Table I.*"—Hodgkinson's tests (page 346). The moment of inertia is 0.0472 in., not 0.472 in., as given in the text.

2. "*Test No. 20 of Table I*" (page 347).—The writer finds some slight discrepancies between his computed deflections and the author's figures.

$$\triangle = \frac{P\,l^2\,\varepsilon}{8\,E\,I - \frac{5}{6}\,P\,l^2} = \frac{P \times 3422.25 \times 0.0675}{8 \times 13\,500\,000 \times 0.74 - \frac{5}{6} \times 3422.25\,P}$$

$$= \frac{231\,P}{79\,920\,000 - 2\,852\,P} = \frac{810\,P}{28\,022 - 10\,000\,P}$$

Load, in pounds.	($\triangle$ in. Writer.	+	V in.)	=	D in. Writer.	D in. Author.	D in. Observed.
3 355	0.01097	+	0	=	0.01097	0.0109	bent.
7 386	0.02419	+	0	=	0.02419	0.0287	0.02
12 970	0.0697	+	0	=	0.0697	0.0686	0·07
19 943	0.2000	+	0	=	0.2000	0.1943	0.20
21 035	0.2439	+	0	=	0.2439	0.2360	0.25
22 127	0.3040	+	0	=	0.3040	0.2800	0.28
23 219	0.3916	+	0	=	0.3916	0.3740	0.37
24 311	0.5225	+	0	=	0.5225	0.5000	0.50 to 0.52
24 857	0.6361	+	0	=	0.6361	0.5940	0.60
25 403	0.7856	+	0	=	0.7856	0.7230	∝ failed.
26 000	1.0410	+	0	=	1.0410	0.9350	

Mr. O'Hanly.

3. "*Test No. 1, of Table VIII*" (page 347).—The writer cannot reconcile the author's $I = 0.367$ in. with his own calculations, of 0.387 in. The computations follow:

$$I = \frac{\pi}{64}\,(h^4 - h'^4) = \frac{1}{20.4}\,(1.78^4 - 1.21^4)$$

$$= \frac{1}{20.4}\,(10.0388 - 2.1436) = \frac{7.895}{20.4} = 0.387;$$

in which h is the external and h' the internal diameter.

Again,

$$I = n'\,b\,h^3 = n'\,h^4$$

$$n' = \frac{1}{20.4}\left(1 - \frac{h'^4}{h^4}\right) = \frac{1}{20.4}\left(1 - \frac{2.1436}{10.0388}\right)$$

$$= \frac{1}{20.4}\,(1 - 0.21353) = \frac{0.78647}{20.4} = 0.03855$$

$$I = 0.03855 \times 10.0388 = 0.387;$$

in which n' is a numerical factor depending on the form of cross-section.

Also,

$$I = q\,c\,h\,a.$$

$$q = \frac{1}{8}\left(1 + \frac{h'^2}{h^2}\right) = \frac{1}{8}\left(1 + \frac{1.4641}{3.1684}\right)$$

$$= \frac{1.4616}{8} = 0.1827.$$

$$I = 0.1827 \times 0.89 \times 1.78 \times 1.367 = 0.3957\,;$$

in which q is a numerical factor depending on the form of cross-section.

$$\Delta = \frac{P\,l^2\,\varepsilon}{8\,E\,I - \frac{5}{6}\,P\,l^2} = \frac{P \times 89^2 \times 0.11}{8 \times 15\,000\,000 \times 0.387 - \frac{5}{6}\,P \times 89^2}$$

$$= \frac{7921 \times 0.11 \times P}{120\,000\,000 \times 0.387 - \frac{5}{6} \times 7921 \times P} = \frac{871.31\,P}{46\,440\,000 - 6601\,P}$$

$$= \frac{1320\,P}{7035 - 10\,000\,P}$$

Load, in pounds.	($\triangle$ in. Writer.	— V in.)	=	D in. Writer.	D in. Author.	D in. Observed.
2 237	0.06154	— 0.03	=	0.03154	0.03655	0.03
2 813	0.088	— 0.03	=	0.058	0.06933	0.07
3 317	0.11776	— 0.03	=	0.08776	0.1005	0.11
3 821	0.15693	— 0.03	=	0.12693	0.147	0.16
4 325	0.21066	— 0.03	=	0.18066	0.2133	0.20
4 829	0.28895	— 0.03	=	0.25895	0.316	0.32
5 333	0.4136	— 0.03	=	0.3836	0.495	0.49
5 585	0.5084	— 0.03	=	0.4784	0.647	not observed; column not allowed to break.
(6 000)	0.77	— 0.03	=	0.74	1.177	

4. "*Test No. 5, of Table VIII*" (page 348). In this case, the writer differs from the author in the value of the moment of inertia. Mr. O'Hanly.

$$I = \frac{\pi}{64}(h^4 - h'^4) = \frac{1}{20.4}(24.7297 - 5.4795)$$

$$= \frac{19.35}{20.4} = 0.9436 \text{ in.}$$

Again,

$$I = n'\, b\, h^3 = n'\, h^4$$

$$n' = \frac{1}{20.4}\left(1 - \frac{h'^4}{h^4}\right) = \frac{1}{20.4}\left(1 = \frac{5.4798}{24.7297}\right)$$

$$= \frac{1}{20.4}(1 - 0.2216) = \frac{0.7786}{20.4} = 0.038157$$

$$I = 0.038157 \times 24.7297 = 0.9436.$$

Also,

$$I = q\, c\, h\, a.$$

$$q = \frac{1}{8}\left(1 + \frac{h'^2}{h^2}\right) = \frac{1}{8}\left(1 + \frac{2.3409}{4.9729}\right)$$

$$= \frac{1}{8}(1 + 0.47) = \frac{1.47}{8} = 0.18375.$$

$$I = 0.18375 \times 1.115 \times 2.23 \times 2.667 = 0.9445.$$

$$\triangle = \frac{P\, l^2\, \varepsilon}{8\, E\, I - \frac{5}{6}\, P\, l^2} = \frac{P \times 7835.8 \times 0.175}{116\,000\,000 \times 0.9436 - \frac{5}{6} \times 7835.8 \times P}$$

$$= \frac{1371.265\, P}{109\,457\,600 - 6530\, P} = \frac{2100\, P}{16\,762 - 10\,000\, P}$$

Load, in pounds.	($\triangle$ in. Writer.	— V in.)	=	D in. Writer.	D in. Author.	D in. Observed.
2 237	0.03223	— 0.025	=	0.00723	0.0097	0.04
4 325	0.073	— 0.025	=	0.048	0.0546	0.06
6 341	0.12777	— 0.025	=	0.10277	0.1165	0.12
8 357	0.208	— 0.025	=	0.183	0.2125	0.22
9 365	0.26587	— 0.025	=	0.24087	0.2835	0.28
10 373	0 3408	— 0.025	=	0.3158	0.379	0.37
11 381	0.6441	— 0.025	=	0.4191	0.5225	0.55
12 137	0.551	— 0.025	=	0.526	0.683	0.69
12 389	0.5963	— 0.025	=	0.5713	0.7275	not observed; column not broken.
13 000	0.7257	— 0.025	=	0.7007	0.97	

5. "*Test No. 15, of Table VIII*" (pages 348-9).

$$I = \frac{\pi}{64}(h^4 - \mathrm{h}'^4) = \frac{1}{20.4}\left(1 - \frac{46.405}{127.455}\right)$$

$$= \frac{81.05}{20.4} = 3.973.$$

Mr. O'Hanly. Again,

$$I = n' \, b \, h^3 = n' \, h^4$$

$$n' = \frac{1}{20.4} = \left(1 - \frac{h'^4}{h^4}\right) = \frac{1}{20.4}\left(1 - \frac{46.405}{127\,455}\right)$$

$$= \frac{0.636}{20.5} = 0.0311765.$$

$$I = 0.0311765 \times 127.455 = 3.973 +$$

Also,

$$I = q \, c \, h \, a.$$

$$q = \frac{1}{8}\left(1 + \frac{h'^2}{h^2}\right) = \frac{1}{8}\left(1 + \frac{6.81}{11.29}\right) = \frac{1.603}{8} = 0.2.$$

$$I = 0.2 \times 1.68 \times 3.36 \times 3.5186 = 3.972 \text{ in.}$$

$$\triangle = \frac{P \, l^2 \, \varepsilon}{8 \, E \, I - \frac{5}{6} P \, l^2} = \frac{P \times 87.39^2 \times 0.16}{8 \times 12\,000\,000 \times 3.973 - \frac{5}{6} P \times 87.39^2}$$

$$= \frac{1221.92 \, P}{351\,408\,500 - 6\,364 \, P} = \frac{1920 \, P}{59\,932 - 10\,000 \, P}$$

Load, in pounds.	($\triangle$ in. Writer.	+ V in.)	=	D in. Writer.	D in. Author.	D in. Observed.
3 355....	0 0114	+ 0.035	=	0.0464	....0.0466...	bent.
16 115....	0.0706	+ 0.035	=	0.1056	....0.1077...	0.09
18 667....	0.08685	+ 0.035	=	0.12185	....0.1245...	0.13
21 729....	0.1092	+ 0.035	=	0.1442	....0.1478...	0.15
24 148....	0.1296	+ 0.035	=	0.1646	....0.1691...	0.17
28 986....	0.1852	+ 0.035	=	0.2202	....0.2222...	0.24
33 824....	0.2487	+ 0.035	=	0.2837	....0.2975...	0.30
37 701....	0.3256	+ 0.035	=	0.3606	....0.3795...	0.38
41 632....	0 4368	+ 0.035	=	0.4718	....0.503 ...	0.48
43 597....	0.5124	+ 0.035	=	0.5474	....0.59 ...	0.59
45 563....	0.6088	+ 0.035	=	0.6438	....0.7 ...	0.67
47 528....	0.7256	+ 0.035	=	0.7606	....0.8525...	0.87
48 511....	0.8155	+ 0.035	=	0.8505	....0.94 ...	0.90
49 494....	0.9094	+ 0.035	=	0.9444	....1.067 ...	1.07
50 477....	1.025	+ 0.035	=	1.06	....1.21 ...	∝

The writer is not aware of any special adaptation of the moment of inertia formula for the case of a hollow column in which the inner circle is eccentric to the outer. He might evolve an approximate one to meet such an exigency; but, where so many of the data have to be guessed at, he considers such refinement uncalled for.

6. "*Test No. 7, of Table III*" (page 349).—The writer has verified the deflections in four cases of this example, viz., first, fourth, sixth and last. His findings, in every instance, agreed with the figures of the text.

7. "*Test No. 204.*—T bar; 1 in. × 1 in. × 87.25 ins. length over all, 1-in. balls and plates, 86.25 ins. effective length = *l*." (page 350).

Mr. O'Hanly.

In Mr. Christie's paper on the "Strength of Wrought-Iron Struts,"* the length of the bar is given as 8 ft. $3\frac{1}{4}$ ins., not 87.25 ins., but 99.25 ins., making the author's effective length $l = 98.25$ ins., not 86.25 ins.

$$I = a\,r^2 = 0.3 \text{ sq. in.} \times 0.26^2 = 0.02028 \text{ in.}^4$$

The other data, as submitted by the author, have been used.

$$\triangle = \frac{P\ l^2 \varepsilon}{8\ E\,I - \frac{5}{6}\,P\ l^2}$$

$$= \frac{P \times 9653 \times 0.0525}{188\,000\,000 \times 0.02028 - \frac{5}{6} \times 9653\ P} = \frac{506.7825\ P}{3\,812\,640 - 8042.5\ P}$$

$$= \frac{630\ P}{474 - 10\,000\ P}$$

Load, in pounds.	($\triangle$ in. Writer.	+ V in.)	= D in. Writer.	D in. Author.	D in. Observed.
100	0.01685	+ 0.025	= 0.04185	0.0372	0.05
200	0.046	+ 0.025	= 0.071	0.0554	0.05
300	0.1086	+ 0.025	= 0.1336	0.0852	0.08
400	0.34	+ 0.025	= 0.365	0.1428	0.15
†(474)	∞	.....	......	......	....
500	....	.....	......	0.301	0.30
550	......	.....	......	0.566	∞

Thus it is seen that the computed deflections of an imaginary column may be made to conform with the recorded tests of a column which went through the mill. How far may this impair confidence?

8. "*Test No. 205*" (page 350).

Load, in pounds.	($\triangle$ in. Writer.	+ V in.)	= D in. Writer.	D in. Author.	D in Observed.
500	0.0003	+ 0.035	= 0.0353	0.0353	0.03
5 000	0.0038	+ 0.035	= 0.0388	0.0388	0.04
10 000	0.009	+ 0.035	= 0.044	0.0441	0.05
15 000	0.0169	+ 0.035	= 0.0519	0.0518	0.05
20 000	0.0295	+ 0.035	= 0.0645	0.0643	0 06
25 000	0.0534	+ 0 035	= 0 0884	0.0876	0.09
30 000	0.1123	+ 0.035	= 0.1473	0.1472	0.15
34 000	0.366	+ 0.035	= 0.401	0.373	not recorded; column failed.
34 110	0 3816	+ 0.035	= 0.4166	0.391	

9. "*Test No. 206*" (page 351).—The writer has verified the first, fourth, eighth and last examples, and found them to agree with the figures in the text.

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* *Transactions*, Am. Soc. C. E., vol. xiii, p. 105.

† With a load of 474 lbs., the deflection is infinite.

Mr. O'Hanly.

10. " *Test No. 208* " (page 351).

Load, in pounds.	(Δ in. Writer.	+ *V* in.) =	*D* in. Writer.	*D* in. Author.	*D* in. Observed.
200	0.00538	+ 0.03 =	0.03538	0.0354	0.02
600	0.01966	+ 0.03 =	0.04966	0.0497	0.05
800	0.02943	+ 0.03 =	0.05943	0.0594	0.06
1 000	0.04193	+ 0.03 =	0.07193	0.0719	0.07
1 200	0.05849	+ 0.03 =	0.08849	0.0884	0.09
1 400	0.08147	+ 0.03 =	0.11147	0.1114	0.12
1 600	0.11552	+ 0.03 =	0.14552	0.1453	0.15
1 800	0.17114	+ 0.03 =	0.20114	0.2010	0.20
2 000	0.27842	+ 0.03 =	0.30842	0.3075	0.30
2 200	0.571	+ 0.03 =	0.601	0.566	∞ failed.
(2 250)	(0.74585	+ 0.03) =	(0.77585)	(0.77)	...
(2 300)	(1.05343	+ 0.03) =	(1.35343)	(0.072)	...

11. " *Test No. 211* " (page 352).

Load, in pounds.	(Δ in. Writer.	+ *V* in.) =	*D* in. Writer.	*D* in. Author.	*D* in. Observed.
500	0.00533	+ 0.02 =	0.02533	0.0253	0.03
2 000	0.02463	+ 0.02 =	0.04463	0.0446	0.05
3 000	0.04117	+ 0.02 =	0.06117	0.0611	0.06
4 000	0.062	+ 0.02 =	0.082	0.0818	0.08
5 000	0.08898	+ 0.02 =	0.10898	0.1086	0.10
6 000	0.12537	+ 0.02 =	0.14537	0.1446	0.15
7 000	0.1771	+ 0.02 =	0.1971	0.196	0.20
8 000	0.2563	+ 0.02 =	0.2763	0.2745	0.27
9 000	0.39378	+ 0.02 =	0.41378	0.409	0.40
9 500	0.50824	+ 0.02 =	0.52824	0.521	not recorded.
9 510	0.511	+ 0.02 =	0.531	0.524	∞ failed.
9 550	0.5226	+ 0.02 =	0.5426	0.536	...

12. " *Test No. 217* " (page 352).—The writer's computed deflections agree with the figures of the text up to load 1 700 lbs., the writer's being 0.002 in. in excess; at 1 750 lbs., 0.0055 in.; and at 1 800 the excess is 0.0024 in.

The thanks of members are justly due to the author for this valuable paper, and he is to be congratulated on the skill, industry and ability displayed in its preparation.

Vol. XXVI. AUGUST, 1900. No. 6.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS AND DISCUSSIONS.

Note.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

A PROPOSED METHOD FOR THE PRESERVATION OF TIMBER.

Discussion.*

By Messrs. Henry G. Prout, J. H. Deghuée, F. W. Skinner, Henry Goldmark, Robert Cartwright, V. G. Bogue, Joseph O. Osgood, Samuel Whinery, Horace J. Howe and William Moncure.

Mr. Prout.

Henry G. Prout, M. Am. Soc. C. E.—This paper presents a proposition which is attractive, novel, and, so far as the speaker is aware, entirely original. Of course, the proposition to prevent the decay of wood by subjecting it to a sterilizing temperature is by no means new. About twelve years ago the process known as vulcanizing was exploited somewhat in New York City on precisely the theory advanced by Mr. Kummer, viz., that subjecting the wood to a high temperature would kill the germs, and that this temperature would solidify the albumen and other constituents of the sap and thus fill the pores of the wood with a solid, impervious, waterproof substance. The wood was treated under a high pressure also, to prevent checking. There should be by this time sufficient experience to show whether or not the expectations have been realized.

A large amount of vulcanized timber was put into use by the Manhattan Elevated Railway, in the tracks, station platforms and possibly elsewhere, ten years ago, or possibly longer. A considerable quantity was also put in service on the New York and Brooklyn

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* This discussion (of the paper by F. A. Kummer, Jun. Am. Soc. C. E., printed in the *Proceedings* for May, 1900) is printed in *Proceedings* in order that the views expressed may be brought before all members of the Society for further discussion. (See rules for publication, *Proceedings*, Vol. xxv, p. 71.)

Communications on this subject received prior to September 22d, 1900, will be printed in a later number of *Proceedings*, and subsequently the whole discussion will be published in *Transactions*.

Mr. Prout. Bridge by Mr. Martin, and a large quantity was shipped to the Northwestern Elevated Railway of Chicago. From all these places we should now be able to get some information as to whether or not the vulcanizing process has any merit.

Obviously, however, the author thinks that vulcanizing is not thoroughly efficient. He must be quite familiar with its results, and yet he proposes to go further and supplement it by the addition of the antiseptic material and also the waterproofing resin. The speaker has always been skeptical as to the results of vulcanizing, because it has seemed inevitable that the transverse strength of the timber would be injured by heating it to such a high temperature.

In the early stages of vulcanizing, R. H. Thurston, M. Am. Soc. C. E., who was then at Stevens' Institute, made some tests of vulcanized sticks and reported that the transverse strength of the timber did not deteriorate under the process. The speaker has heard nothing further as to those results since Professor Thurston's tests.

Were it not for Mr. Kummer's statement, the speaker would also feel skeptical as to whether or not such a quantity of resin can be forced into the timber.

It is obvious that the high temperature treatment will develop checks in the timber—checks which are otherwise there, or would otherwise occur—and that those checks will be filled with creosote and resin which will, undoubtedly, add to the life of the timber.

The most important question is whether or not timber is actually injured by subjecting it to a temperature of about 300°, under pressure.

Mr. Deghuée. J. H. Deghuée, Esq.—Vulcanized wood, with which the speaker has had some experience, has been used for the past 12 or 15 years. The wood was heated to a temperature of about 85° under a pressure of about 90 lbs. It has never been found that this treatment injured the fiber of the wood in the least. The speaker has seen the tests made by Professor Thurston and by others, and these tests showed that the timber was strengthened. The difficulty found with vulcanized wood was, that when it began to decay, that decay began at the surface, not at the heart. The sterilizing treatment was sufficient in that respect, and whenever decay began it was caused by contamination from outside, evidently by being washed by the rain water.

The process described by the author seems to be especially adapted to overcome that difficulty. It produces practically vulcanized wood with an antiseptic shell. It would seem that, as the heart of vulcanized wood never decays and an efficient antiseptic shell is provided, the process not only overcomes the troubles encountered with vulcanized timber, but also the objections to ordinary creosoted wood. In the latter, the objection is reversed, as the wood frequently decays at the heart on account of imperfect sterilization. Another objection is

Mr. Deghuée. that it is soft, and does not resist the crushing strain. Creosote, although it may not be soluble, is washed out, perhaps by the mechanical action of the water. The speaker has experimented with wood treated by the process described in the paper, and has found that it actually shed water, the water running in drops on the surface. He has made soaking tests of the wood, and found that absolutely none of the material will dissolve. After soaking the wood for three or four weeks it was impossible to detect any of the preservative material in the water.

The term vulcanizing is probably only a trade name, given to the treatment on account of its being a heating process. In vulcanizing it has seemed to the speaker that the treatment is primarily a sterilizing process—simply a thorough sterilization of the wood—the secondary action being the decomposition of the sap and the production of a small quantity of wood tar creosote in the sap of the wood. This creosote is antiseptic, but the amount is rather small, and it has been found that it was not sufficient to prevent external contamination; that a fungus could grow in the wood if it could penetrate it from the surface, and that in time the surface would begin to decay. It is also probable that these antiseptic bodies which were produced by the heating were not strong enough to prevent that decay.

The theory that the elements of the sap were hardened and filled the pores with impervious substance has not been verified.

Mr. Skinner. Frank W. Skinner, M. Am. Soc. C. E.—This paper gives an interesting description of a process which seems to be admirably adapted to secure the ends which are sought.

The principal requirements in connection with the process are: The seasoning of the wood and its sterilization at a high temperature, the extraction of the volatile substances in the timber, the operation of the vacuum for withdrawing the air, and injecting an antiseptic and waterproof substance. The question as to whether or not all these processes are desirable, are harmless or are beneficial, should be considered. The weight of evidence presented seems to be that the degree of heat maintained in seasoning and sterilizing is not to be considered as detrimental to the fiber or the strength of the timber.

The question as to whether or not the removal of all the volatile oils in the timber is detrimental has not yet been raised. The speaker doubts the advantage of removing them. He has positive assurances, from those whose investigations and judgment he greatly respects, that the extraction of all the juices of the timber impairs its strength and makes it brash. That point is worthy of discussion. Supposing that, however, to be settled in either way, we obtain a piece of timber which is supposed to have been sterilized; that is, admitting the decay of the timber to be due to bacterial agencies, the bacteria are all

Mr. Skinner. killed. After this the injection of the antiseptic material seems to be somewhat supererogatory. If the timber is to be filled with antiseptic material, why need it be sterilized first? If the material is an antiseptic, it should be an efficient one without sterilization, and it would seem that Mr. Kummer's formula for an antiseptic is likely to give very good results. The waterproofing and the constituents of the liquid seem to be desirable, and the speaker agrees with Mr. Nichols that it seems likely that the process should be preservative and increase the durability of the timber.

There are one or two points in reference to the manufacture which the author should make clear. In the first pressure treatment of the timber, is pneumatic pressure applied? Apparently, no liquid or water is introduced; so that it may be inferred that the first is an air process. Secondly, the schedule of time required for the treatment of the timber is stated to be twelve hours. Is that twelve hours of net time or of gross time? Can a charge of timber be brought from stock at 6 A. M. of a given day and be turned out as a finished product at 6 P. M. of the same day? If so, the process is materially more rapid than most of those with which we are familiar.

There is one point in the paper to which the speaker is obliged to take exception, viz., the statement that the impregnation with an antiseptic fluid is very difficult or impossible in the case of large timber. There is to-day established in Philadelphia a company which impregnates, to a hitherto undreamed-of extent, hard and soft timber of any merchantable size, 12 x 12 ins. or greater, right to the core. In that process a piece of timber is put in a retort and saturated to 120% in from 40 minutes to three hours according to its thickness. A piece of white pine 1 in. thick can be saturated to 120% in 40 minutes, and a timber 10 ins. square is saturated to the same percentage in a little less than three hours. The treatment of hard wood requires about 40% more time. By 120% saturation it is meant that a stick of timber weighing 100 lbs. when put in the retort will weigh 220 lbs. when removed. This is effected in a closed retort by means of very heavy hydraulic pressure, about 500 lbs. for working pressure, and as high as 1 000 lbs. if necessary, and the apparatus is such that this pressure can be applied in a very few minutes. In a treatment, which the speaker witnessed, some pieces of timber were inserted in the retort, saturated to nearly 200% and taken out in 63 minutes, and the retort was ready for another charge. That is, a round trip was made in about an hour, so that the injection of antiseptic fluid can be made to the heart of timber of any size in length and cross-section. That process of complete impregnation, together with the formula and materials described in the paper, might lead to exceedingly valuable results. It might obviate the necessity of sterilization and possibly the necessity of high temperature in seasoning.

Mr. Skinner.

The high-pressure process, just described, is not used for wood preservation, but for the purpose of making the wood non-inflammable. The speaker has made pine wood shavings $\frac{1}{64}$th of an inch in thickness, has placed a spoonful of them on a platinum plate and put that over a Bunsen burner and held it there in the fiercest flame for probably 10 minutes. It was not consumed; it was blackened and could be crumbled easily, but under no circumstances would it blaze. A block of wood 2 or 3 ins. thick, and thus treated, was placed in the furnace of a steam boiler and left there over night. In the morning it was charred on the outside, but had not been consumed.

Mr. Goldmark.

Henry Goldmark, M. Am. Soc. C. E.—A comparison between the cost of the process described by the author and that of the improved chloride of zinc method would be interesting and instructive. There is little doubt that the injection of creosote preserves the timber longer, and under more unfavorable conditions, than any other process. It is, however, by far the most expensive means of protection.

The whole question of timber preservation is, after all, one of economy. The point is, not whether the ordinary or an improved creosote process is the best thing, but whether something else much cheaper will not, at least for railroad ties, serve a useful purpose. The German railroads have had an extended experience for many years with the Rutgers process. This consists in injecting chloride of zinc, with the addition of a small percentage of dead oil of tar. The theory of the method is, that the dead oil of tar will prevent the zinc salt, which is soluble in water, from being washed out.

The results, as given out by the company which does most of the work, are extremely favorable. They are based on official investigations by the German government, and are believed to be reliable.

The cost of this improved zinc process is so much less than that of creosoting that it is more likely to be adopted on a large scale in this country than more expensive methods.

Mr. Cartwright.

Robert Cartwright, M. Am. Soc. C. E.—The preservation of wood is very desirable, provided it can be accomplished at a minor expense. The speaker at one time burnettized a great deal of bridge timber. The process consisted of enclosing the timber in a tight receptacle and boiling out, as it were, the pyroligneous acid. Of course, being under pressure and in a water-tight, hermetically sealed tank, there was no opportunity for the oxygen to get at the acid. The hot water dissolved the acid and was then drawn off. Dry heat was then applied and a solution of sulphate of zinc was introduced under pressure and thereby injected into the tubes forming the wood fiber.

The speaker has frequently used a second time the clamps and keys from a worn-out bridge. The Indians frequently stole the ordinary timber, but would not touch the burnettized sticks, because they could not saw them nor split them, and the wood would not burn.

Mr. Cartwright. The burnettizing process, however, was very expensive, and to-day the object is to get the best preservative for the least amount of money. It is said that the process described in the paper is economical, and this is a point in its favor.

Mr. Bogue. V. G. Bogue, M. Am. Soc. C. E. (by letter).—Notwithstanding all the creditable work which has been done, we must confess, that, during the last 15 or 20 years, there has been but little absolute progress in the science of wood preservation. We know that the creosoting process is the most reliable, but no process has yet been discovered which can be fully depended upon in all situations and for all varieties or classes of timber.

The author states that the results obtained with creosote do not indicate that after treatment there often occurs such cracking or checking as to expose the untreated, heart portions of the timber to decay. This is contrary to the writer's observations. Only recently, in making some railroad examinations, he has found that, in the majority of instances, where creosoted piles had decayed, the trouble was clearly caused by checks which had occurred after the structures had been built. If the sterilizing process will quite fully develop the checks, without working damage to the timber, so that when the creosote is turned on it will reach all portions of the material which the air would ever be likely to reach, we may have in Mr. Kummer's suggestion a distinct advance. The writer would like to see the suggestion tried on a scale large enough to prove its value.

Mr. Osgood. Joseph O. Osgood, M. Am. Soc. C. E. (by letter).—This subject is an important one to all engineers who are called upon to protect timber from the teredo or from decay, and has been treated by Mr. Kummer in a clear and interesting manner.

If ties could be used without driving spikes or boring holes in them, the method of treatment suggested would probably prove more effectual than under present conditions of service.

If the penetration of the antiseptic material is only about 1 in. from the sides of the tie and 6 to 8 ins. at the ends, only half the tie is treated at the section where the spike holes occur, and decay at those points is not long delayed.

It is noticeable that a good quality of long leaf yellow pine has been selected for the experiments. The heart of this timber is full of resin and is fairly durable without treatment. It is said, however, by those who make a business of treating timber, to be much less suitable for the purpose than the woods of more porous structure, and which, untreated, decay much sooner, but which will take up a much larger amount of the creosote or other treating material.

It would seem to be entirely reasonable that the injection of resin with the creosote should make the surface harder, and might serve to keep the creosote from washing out, but it would tend to lessen the effectiveness of the creosote as an antiseptic, and it does not seem probable Mr. Osgood. that it would be at all effective against the teredo, which eats the resinous heart of long leaf timber with great avidity and requires a very strong dose of creosote oil to affect its appetite.

It has been stated that all decay in timber begins at the outside of the stick. This statement would seem to be subject to some modification, as it is not uncommon to find oak sticks hard on the exterior surface and rotten inside; and even long leaf yellow pine is frequently destroyed by what is known as "red heart," a fungous disease, in which the heart of the stick is most affected.

As to forcing creosote into long leaf pine for protection against the teredo: this is now done effectively by the Galveston Wharf Company at Galveston, only creosoted piles being used in the main wharves of that company, and these, the writer is informed, give satisfaction. It is said that these are impregnated with the heavier oils of coal tar to the extent of from 20 to upwards of 25 lbs. per cubic foot, and the writer is informed by the Manager of the Creosoting Company which treated the piles for the present pile bridge of the Gulf, Colorado & Santa Fé R. R., across Galveston Bay, built a number of years ago, that 27 lbs. of heavy dead oil per cubic foot was used in them, or in as many of them as would take that amount.

Long leaf yellow pine, when thoroughly creosoted, generally shows little of the heart wood which is not distinctly colored by the oil, although, in the piles coming under the writer's observation, there has always been some untreated heart. The timber appears to be much weakened by the process, and thoroughly creosoted piles will sometimes break in handling, under circumstances which would not injure an untreated stick of the same timber. The timber seems to be very brittle. The great objection to creosoted timber at present is the expense. Inquiry, three years ago, when several thousand piles were required in a bulkhead to retain a filled wharf at Sabine, Tex., showed that the piles, which then cost about 6 cents per lineal foot delivered, would have cost over 40 cents per foot, if creosoted.

In treating piles great expense is caused by having to treat the whole length. Treatment is undesirable for the portion in the ground, where the teredo does not work, and is usually unnecessary above the water, so that it frequently happens that more than half the length of the pile is treated without any special benefit. Various ways of overcoming this difficulty, and of using creosote without distributing it where not needed, have been suggested, and some of them tried. Experiments are now being made with piles which have a 1½ or 2-in. hole bored through the center of each stick from the top to a little below the surface of the water, these holes being filled with creosote oil from time to time. The oil gradually distributes itself outward and downward, and, if this goes on rapidly and thoroughly enough, will, Mr. Osgood. it is argued, reach the exposed surfaces of the piles and prevent the ravages of the teredo.

An attempt has also been made to stop the progress of the teredo, in piles already slightly affected, by boring a slanting hole at about mean low water and reaching down as far as possible without going through the stick. These holes, of 1 or 1¼ ins. diameter, are filled with creosote oil at intervals as the tide permits and as the oil soaks away. The holes are kept plugged at the top to prevent waste. It is too early to determine whether either of these experiments will prove effective or of any value.

A writer in one of the engineering periodicals not long since called attention to a method of forcing liquids into timber through a cap on one end of the stick, which permitted a pressure to be applied to force the liquid lengthwise through the pores of the wood. This would seem to offer advantages in treating piles, as the process could be stopped when any portion of the length had been saturated, and probably a hole bored in the middle of the stick, nearly as far down as it was desired to distribute the oil, would be of service in this connection.

Mr. Whinery. SAMUEL WHINERY, M. Am. Soc. C. E. (by letter).—In discussing any method for the preservation of timber, the conditions under which the wood is to be used must be considered, and the character and extent of the preservative process should be suited to resist the causes of disintegration to which the wood will be subjected.

When exposed to brackish water, wood must be protected against the ravages, both of ordinary decay and of the teredo. When used for railroad ties, and generally for structures on land, it is necessary to make provision against ordinary decay only. For the latter purpose it would seem that any process which, like that under consideration, first thoroughly sterilizes the timber throughout its whole mass, and then fills the cells to a greater or less depth from the surface with a permanent material which will exclude air and moisture, would prove efficient. It is not even necessary that the sealing material should penetrate the wood at all if the surface can be made impervious to air and moisture and maintained in that condition. If these assumptions are well founded, wood-preserving processes may cover a wide latitude, and there should yet be plenty of room for invention. The modified process of creosoting wood described by Mr. Kummer is rational, and should be efficient, particularly in preserving railroad ties.

Those who have had occasion to work in the yellow pine forests of the Southern States know that the endurance of the "pine knots" is proverbial. When the public lands of those States were originally surveyed by the Government, these pine knots were frequently used for corner stakes or monuments, and they have often been found in place in a perfect state of preservation after being in the ground for more than thirty years. The principal peculiarity of these knots is that they are often perfectly saturated with pine resin, and their practical indestructibility is, without doubt, due to that fact. The process under discussion seems to be an approach to this wood-preserving process of Nature. Mr. Whinery.

Mr. Howe. HORACE J. HOWE, M. Am. Soc. C. E. (by letter).—Referring to the tie question and the apparently prohibitory cost of treating the whole tie, it should be borne in mind that the life of the tie is the life of the portions adjoining the rails, and that in first-class, well drained ballast it is the top half of the stick at those points which suffers most, and necessitates renewal. Cannot a method of treating them be devised under these conditions?

In looking over piles of old ties taken from the track, one is struck with the fair condition, in most cases, of the middle portion of the tie, say for 4 ft. in length. The ends are split, owing to various causes, one of which is that trackmen, in originally placing the new tie, are allowed to use picks freely. Thus the ends are split off, and, naturally, cracks develop and rot sets in near the rails.

The heart of the tie being on the under side requires less attention than the top. Let the tie be dapped under each rail for 12 ins. in length, and let four spike holes at each end be bored by template for the pattern of rail to be used. It is stated by W. W. Curtis,* M. Am. Soc. C. E., that this can be done, in connection with the treatment, at a cost of about 3 cents per tie. Could not each tie be treated at these two places for a total length of 2 ft., with or without an isolating chamber?

The holes would distribute the preservative to the points where it was most needed, and the waterproof quality of Mr. Kummer's mixture, for instance, would take effect on top.

It looks as if the expense might be reduced considerably, say one-third, in comparison with the corresponding treatment of the whole tie.

It might be said that the tie would be unfavorably affected by difference in homogeneity, but this would have to be determined exactly by experiment.

Mr. Moncure. WILLIAM MONCURE, M. Am. Soc. C. E. (by letter).—The preservation of timber is a subject which has been discussed extensively, but, as yet, there seems to be no method by which the cost is brought within practical limits. The cost of the method proposed by Mr. Kummer is not given.

In 1886, in the construction of one of the southern railroads, all the signal and mile-posts were made of long leaf North Carolina pine, the entire log being used, without any regard to the quantity of sap or heart. These posts were 4 by 6 ins., and the part above ground

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* *Transactions*, Am. Soc. C. E., Vol. xlii, page 373.

Mr. Moncure. was painted with three coats of white lead in linseed oil. The lower part, up to a point just above the surface of the ground, was placed for 15 or 20 minutes in an open kettle containing 50 % of pine tar and 50% of resin, the mixture being kept above the boiling point. These posts are standing now, and when examined two years ago showed no signs of decay. The cost of this process did not exceed 15 cents for each post. It is possible that the wood was thoroughly dried by the heat, and that the tar and resin filled the outer pores, leaving also a coat outside which prevented the entrance of moisture.

The oak tie, without doubt, is best suited for roads where there is heavy traffic and much curvature, and seems to be the most difficult to preserve by the creosoting or any similar process. Investigations seem to have been directed almost entirely to creosoting or similar processes, and, so far, seemingly without practical results. It is possible that if investigations were made in the direction of drying the timber and coating the outside with a substance which would prevent the entrance of moisture, some method might be found which would bring the cost within a practical limit. There is a cypress in some of the Southern States which has been used for ties and has lasted for 25 years, but cypress is objectionable because the wood is soft; the rail cuts the tie, and the spikes do not stay in place, thus causing the track to get out of gauge. These objections can be overcome by the proper use of tie-plates, and a cypress tie with tie-plates ought to especially recommend itself to roads on which the curvature, gradients and traffic are light.

The question of obtaining ties is at present of great importance to the maintenance-of-way departments of railroads, and these notes are presented with the hope that this subject will be continually kept in view and result in developing some practical method which will be within the means of any railroad.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS AND DISCUSSIONS.

Note.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

HEIGHT OF BUILDINGS.

An informal Discussion at the Annual Convention, July 2d, 1900.*

Subjects for Discussion:

(1) "What Considerations Should Limit the Height of Buildings?"

(2) "Do Recent Developments in Construction, Sanitation, Intercommunication and Economy of Administration, warrant the Removal of all Restrictions?"

By Messrs. Corydon T. Purdy and Reginald Pelham Bolton.

Corydon T. Purdy, M. Am. Soc. C. E. (by letter).—High buildings are the outgrowth of commercial considerations. They facilitate business, they increase ground rentals, and they offer opportunity for profitable investment. Mr. Purdy.

As the American mind is not hampered by precedent or biased by ancient customs, these considerations have easily outweighed popular prejudice, and even small American cities aspire to high buildings. In Europe, there is more conservatism, but all the world is now striving for commercial advantage, and the pressure to make buildings larger and higher will probably increase there as it has in America.

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* The discussion of this subject, for which no formal paper was presented, is printed in *Proceedings* in order that the views expressed may be brought before all members of the Society for further discussion. (See rules for publication, *Proceedings*, Vol. xxv, p. 71.)

A number of discussions on this subject, presented at the Convention, were not received in time to permit of preparing them for this number of *Proceedings*. They will appear in a subsequent number.

Communications on this subject received prior to September 22d, 1900, will be printed in a later number of *Proceedings*, and subsequently the whole discussion will be published in *Transactions*.

Mr. Purdy. The problem as to whether or not the removal of restrictions as to height is warranted must be faced. The question is pertinent, therefore, in both Europe and America.

It is the writer's purpose merely to outline for discussion this topic: "The Limitation of the Height of Buildings," and to mention some of the points of interest exhibited by the photographs. Plate XXX, Fig. 1, is a view of New York City, from the North River, well south toward the Battery. In less than a generation, high buildings have changed the sky line of this part of the city completely. A few years ago the regulation five-story building line was unbroken except by the towers of churches. At present, Trinity spire, for many years the highest structure in America, is looked down upon from the office windows of Wall Street and Broadway.

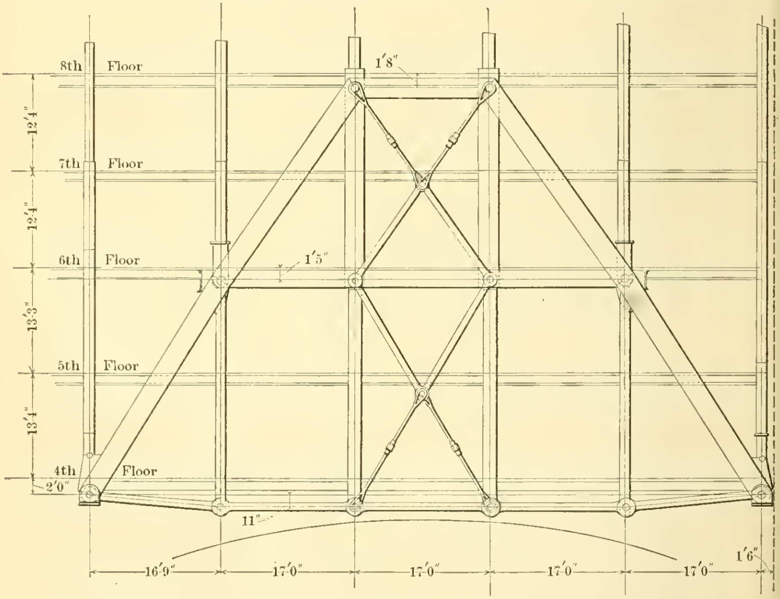

Fig. 1.

Many of the constructive problems in steel buildings are complicated in character, and they are not only so because of the variety of loads and strains which are sometimes involved, but because all lines of construction have to be worked out with reference to the uses of the building, the arrangement of its interior walls, and their openings.

The arrangement of the trusses over the great ballroom in the

PLATE XXX.
PAPERS, AM. SOC. C. E.
AUGUST, 1900.
PURDY ON HIGH BUILDINGS

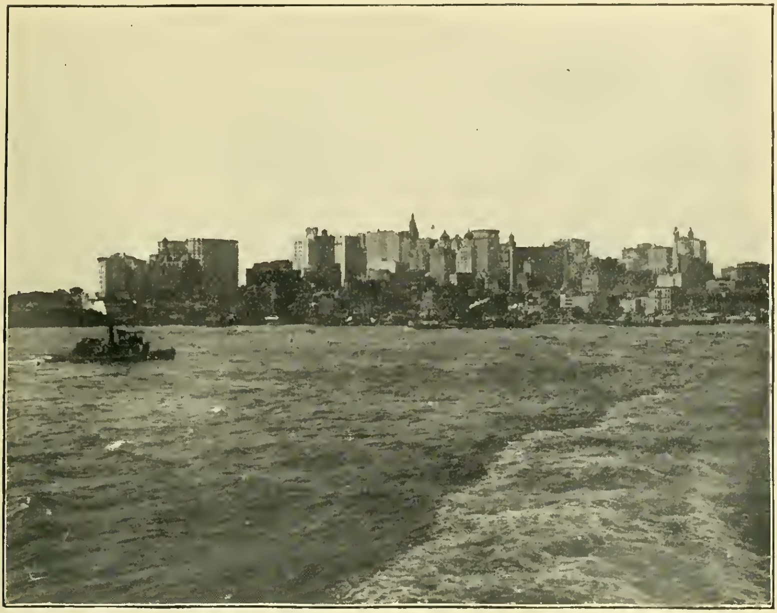

Fig. 1.—Sky Line of Lower New York City.

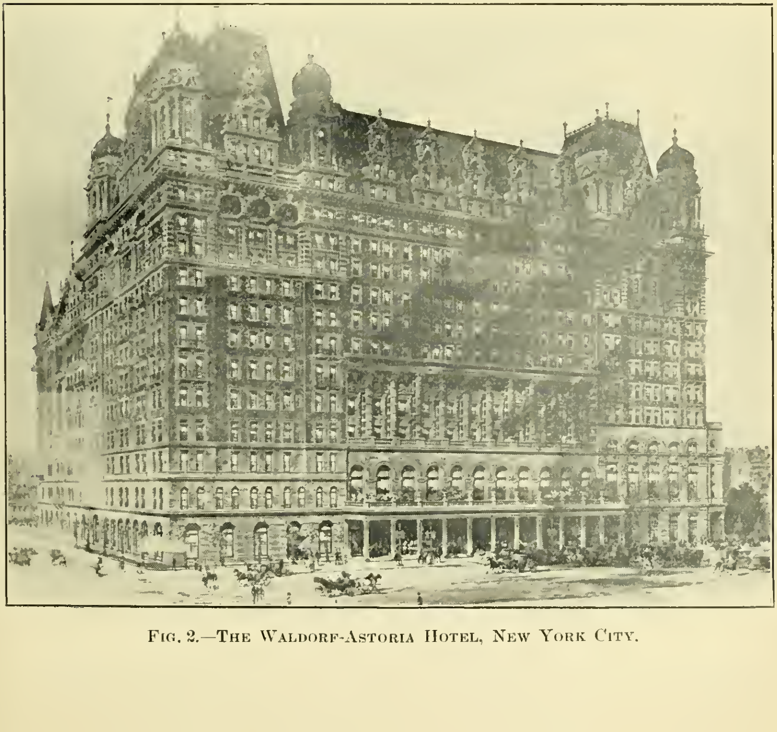

Fig. 2.—The Waldorf-Astoria Hotel, New York City.

Waldorf-Astoria Hotel in New York City, is a marked illustration. Mr. Purdy The lines of these trusses are shown in Fig. 1. The ballroom is 100 ft. long and 85 ft. wide and is without columns. It is three stories high. There are two great trusses sandwiched into the interior walls of the four stories directly over the ballroom, and their construction is worked out in such a way that their presence would never be suspected by people occupying the rooms immediately adjoining them. They carry 12 stories of bedrooms, weighing, with a reasonable allowance for live load, some 20 000 000 lbs. Some members of the trusses are heavier than can be found in any other structure in America. The lower chords are made up of nests of 12-in. I-bars carried on 12-in. pins. There is also one girder in this building 35 ft. long, which weighs 85 tons, and one column which carries 5 400 000 lbs.

The completed Waldorf-Astoria Hotel, Plate XXX, Fig. 2, is the largest and finest structure of its kind in America, and possibly in the world. It cost about $5 000 000.

The Old Colony Building, Plate XXXI, Fig. 1, is one of the notable structures in Chicago. While it is narrow and high, it is also one of the stiffest high buildings constructed in that city. The scheme for the stiffening or bracing consists of four vertical lines located equidistant from the axis of the building. The portals, shown in Fig. 2, are placed one on top of another in such a way that the shear is conveyed directly from one to the other, and the columns are practically incorporated with the portals as a part of them. Their chief advantage is in the opening they afford between rooms. For all practical purposes they do not divide the space at all, and yet the desired bracing is obtained.

The exterior walls of this building were in process of construction at different heights at the same time (Plate XXXI, Fig. 2). This cannot be done in buildings of massive construction. The new building for the North American Trust Company, Plate XXXII, Fig. 2, recently completed on the corner of Cedar Street and Broadway, New York City, was built in the same way. Plate XXXII, Fig. 1, shows the completed building and also affords an excellent illustration of the splendid light areas which can be put in buildings of this kind.

Some buildings are built too high for their width. That at the corner of Wall and Nassau Streets, in New York City, Plate XXXIII, Fig. 1, might be mentioned as one of this class.

The highest building in America is that known as the Syndicate Building on Park Row, in New York City. It is shown on Plate XXXIII, Fig. 2.

The Broadway Chambers, Plate XXXIII, Fig. 3, is another of the new high buildings in New York City. This building is exhibited by models at the Paris Exposition, where every feature of its construction is illustrated.

Mr. Purdy. Where buildings are now limited, the limitation is due to one or more of four things:

(1) Legal enactment;

(2) Economic considerations;

(3) Conditions of construction, concerning which law may not specify; and

(4) Popular prejudice.

In New York City the only legal limitation to the height of fireproof buildings is a provision that the overturning moment due to wind pressure shall not exceed 75% of the moment of stability, with the wind pressure taken at 30 lbs. per square foot, over every square foot of surface exposed. In Chicago the legal restriction has recently been fixed at 135 ft.

There are many things to consider in either fixing or removing restrictions to the height of buildings by law. First of all there is popular prejudice. Then there are:

The disturbing effect on land values;

The exclusion of sunlight from the streets;

The congestion of traffic;

The increased difficulty of fire protection;

The overburdening of established water supplies;

The inadequacy of drainage and sewers already constructed;

The disturbing effects on the business of building trades, architects, engineers and contractors; and last, but not least,

Æsthetic considerations.

Some of these considerations are more important than others, but all bear upon the problem. The writer believes that the height of buildings should have a reasonable limitation, but it seems to him that most of the real objections to the so-called "sky scrapers" do not hold with much force against buildings of fourteen or fifteen stories, or less.

High buildings have become possible through the use of new materials, the new use of old materials, notably the use of steel, and the development of the elevator.

It is also worth noting that the new buildings are better and simpler than the old ones.

They have more light.

The interior arrangement may be made in any way which may be desired and that arrangement can be changed at any time if desired; while

The strength of the building is in the steel frame, and that strength is susceptible of accurate computation, which brings with it a simplification of all problems of construction.

In conclusion, the writer desires to call the attention of our members to the fact that though in America we have wonderfully

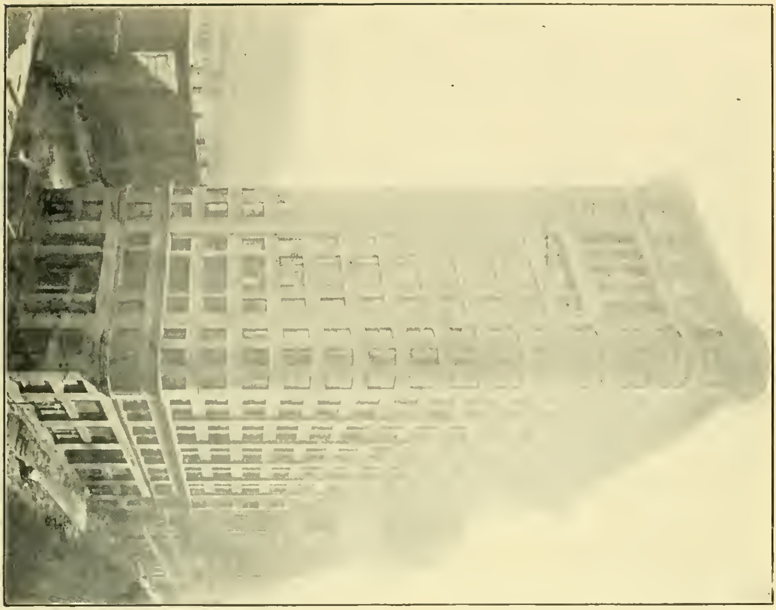

Fig. 1.—The Old Colony Building, Chicago

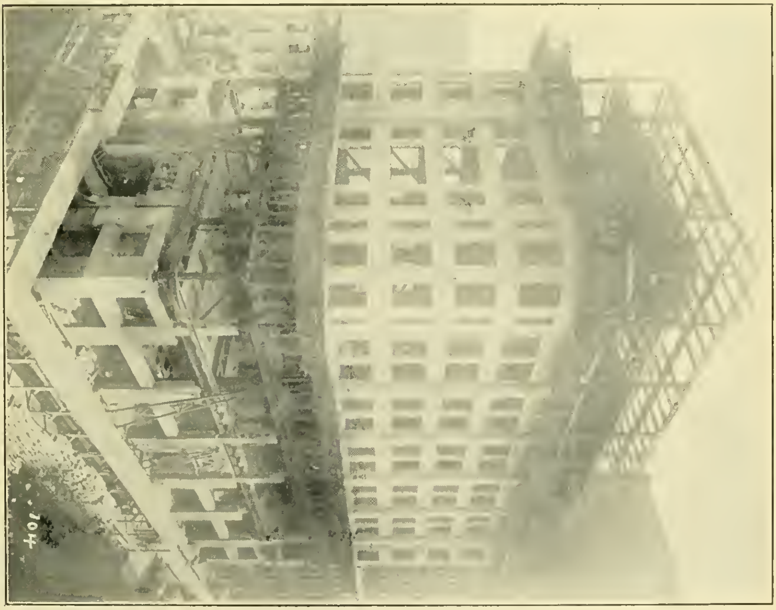

Fig. 2.—The Old Colony Building during Construction.

Mr. Purdy.

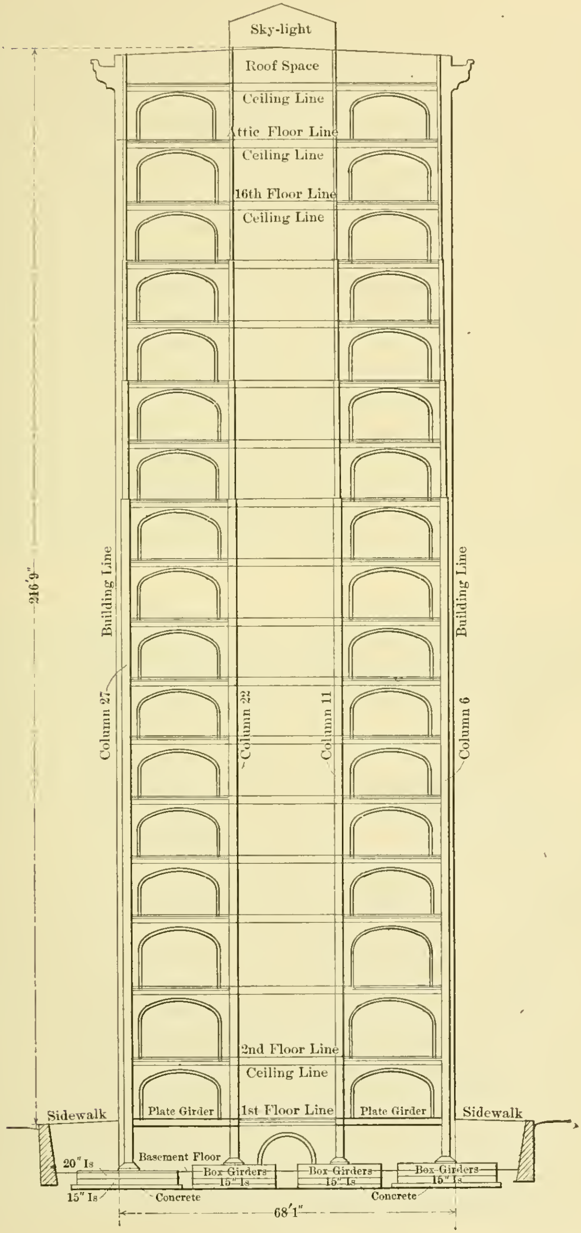

FIG. 2.

Mr. Purdy. developed the steel-constructed building, we owe a great debt to Europe for many of the ideas which have been used therein. It would be generally correct to say that European engineers have invented and Americans have developed.

One instance of this is sufficient to illustrate. As long ago as 1854, an asylum was constructed at York, England, by the Society of Friends, in which the floors were made of flat hollow terra cotta arches, of almost exactly the same pattern as we are now putting into our office buildings. They were designed by Mr. Pritchett, an Englishman. It has been repeatedly claimed by American writers that this arch was of American origin, but the first arch of this character was not constructed in America until 1873. Mr. Pritchett carried his arches over spans of 4 ft. 6 ins., which also accords with present practice. They were carried on cast-iron beams. The rolled beam had only been invented a year or two before

Mr. Bolton. Reginald Pelham Bolton, M. Am. Soc. C. E. (by letter).—The writer's professional connection with the equipment of large office buildings and hotels in New York City leads him to the conclusion that the limitation of the height of buildings should be left to practical and economic action, and that legislation or municipal interference cannot produce desirable results.

The law of England, protective of the right of so-called "ancient light," has operated to prevent the development of buildings and their consequent improvement. Progressive increase in the value of land in business centers will operate to the disadvantage of tenants unless relief be given in the only possible direction, viz., upward.

Concentration of trades and of business in certain centers is desirable and economical, and the advantage of the community at large is advanced thereby. Therefore an inconvenience which may temporarily operate to the disadvantage of individuals should be endured if the general welfare is advanced.

The writer believes that these general propositions will meet endorsement, but, in this particular class of public improvements, it is clear that the apparent inconveniences are more imaginary than real.

It is true that in a country where the proportion of bright daylight is limited, the value of window light is not to be lightly estimated, but modern methods of artificial light have so advanced as to greatly discount the positive necessity of window light.

Further, in the construction of a higher class of buildings, in a city such as London, the primary steps are sure to be soon followed by a general increase. The "city" has been, within the writer's memory, practically reconstructed from a three and four-story basis, to a height of five to seven stories without general inconvenience, and the advantages of a single lofty structure would be so soon grasped

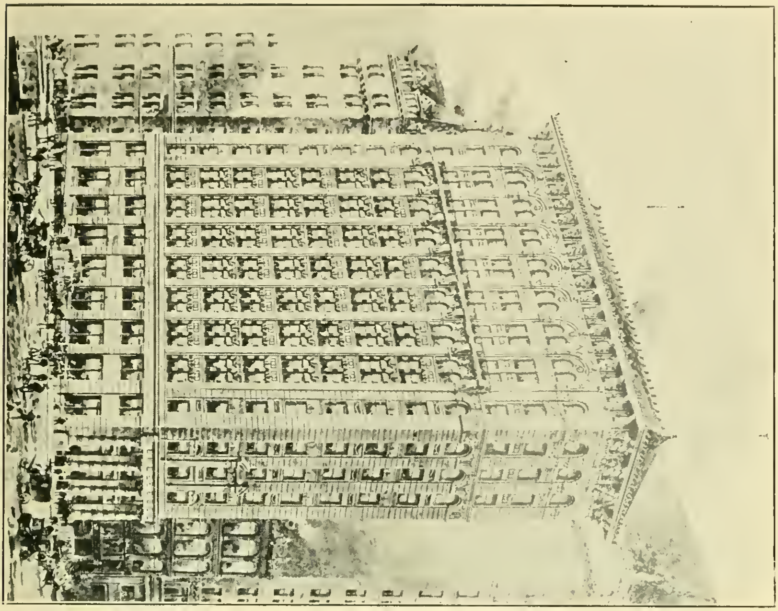

FIG. 1.—NORTH AMERICAN TRUST BUILDING, NEW YORK CITY.

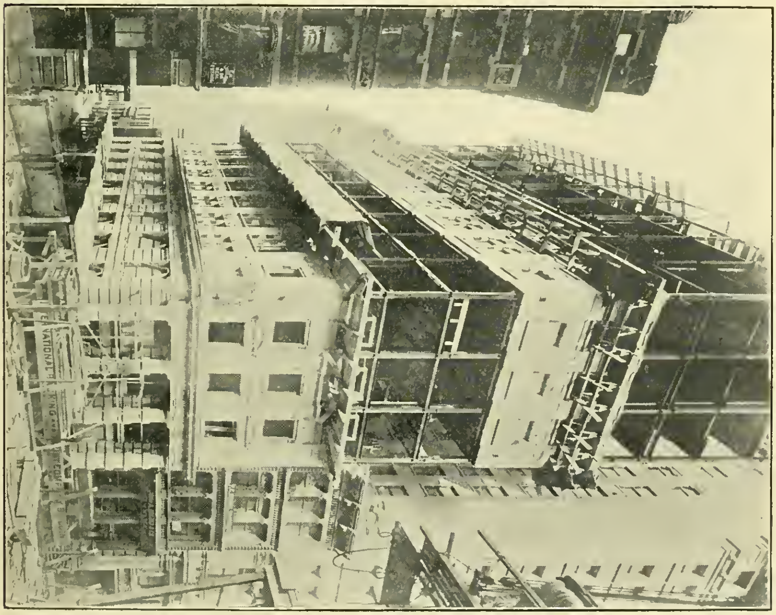

FIG. 2.—NORTH AMERICAN TRUST BUILDING DURING CONSTRUCTION.

that it would not be long before a general reconstruction of greater height took place. Mr. Bolton.

The construction of a tall building on a neighboring lot, while temporarily interfering with the immediate supply of light and, possibly, to some extent, of air; enhances the value of the neighboring properties, since on its success they become equally capable of increased development.

In the case of large office and hotel buildings the interior economy is such that artificial light and air supply can be and are generated at extremely low cost, less than is possible by public companies. Therefore a supply of both could be afforded to neighbors, in this way making up to them their temporary deprivations.

There cannot be any question that the general sanitation of a district is improved to an important extent by the construction of tall buildings, inferring, as this does, the effect of deep underground excavation and sub-soil drainage.

The writer can refer to instances in New York illustrative of this. When the Bowling Green Offices were constructed, the excavation extended 30 ft. below grade, and the sub-soil drainage was found to be extensive. Examination proved that a large part of it came from defective sewerage of the neighboring old buildings, the house sewer of one of which, a public restaurant, was found to be broken and choked.

This menace to health is, of course, now entirely removed by the sub-basement drainage system of the offices. Such cases could be multiplied indefinitely, and include wet walls and cellars dried, and insecure buildings supported and improved by neighboring structures of greater height and depth.

The relative increase in value of a piece of land, by reason of the construction of a lofty neighbor, may be gathered from what has proved to be the case in New York City.

Land, which with four-story buildings has barely paid expenses and taxation, has, with a lofty building, been able to earn all expenses; pay interest at the rate of 4% upon mortgages, the extent of which greatly exceeds the value of the original buildings; also pay a largely increased taxation, sometimes as much as five times the old rating; and, finally, leave a substantial profit on the net capital invested. The taxation borne by a certain property is relieved by the additional taxation placed upon an enlarged neighbor.

The writer believes that recent developments in construction, sanitation, intercommunication and economy of administration, warrant the removal of all restrictions, and further, he presents the proposition that natural causes will act as a restriction against excessive heights unless accompanied by proportionate areas. One of these is due to the limitations imposed by elevator service.

Mr. Bolton. The tall buildings which, in New York, have been the subject of most criticism, are chiefly those which, on a very confined area, rise to an extreme height. Their appearance, especially on the dead sides, is unsightly, and the architectural effects are almost ludicrous. The most flagrant example is the St. Paul Building, which has, perhaps, caused more criticism of the lofty building than any other.

It is in such buildings that the tenants of upper floors find their means of access of less convenience than elsewhere. For instance, in the building referred to, six elevators are installed, two serving the lower eight floors, two the intermediate, and two the upper eight floors. Each part of the building, therefore, is practically a portion of an eight-story structure, having only two elevators, a number certainly inadequate in comparison with others of equal height elsewhere. Moreover, the upper set of floors must be reached by a ride of 200 ft., equivalent to its location at that distance away from the main street.

The failure of architects to grasp the statistics of vertical traffic is not to be wondered at, the extraordinary feature being their attempt to deal with such a subject. They have not, as a class, learned that the necessary proportion of elevator mileage demands for a certain height a certain area, in which combination the proportions of a very high building becomes less offensive.

Further, the cost of maintenance of the upper floors in extremely high buildings is often disproportionate to their returns. These floors demand an excessive amount of heat for the winter season and increase the cost of house-water pumping. In addition, they must be debited with the larger proportion of the cost of the elevator service, and all these things being considered, they should produce a rental proportionately higher than floors below them. Such a proportionate increase is seldom applied, although some upper rooms are leased at high prices on account of the views they command, and their freedom from street noises. These features, and the elevation above the heated streets in summer, are found to be so well worth paying for, as to be the cause of the willingness of tenants to reside at an increased distance from the street.

The general conveniences of modern office and hotel buildings are so great as to justify much greater inconveniences than they cause.

The sanitary improvement over old and low buildings is great, and security from fire and increase of air space per tenant are worth general consideration.

It is due to the increase of size by means of height that mechanical improvements can be introduced which would otherwise be impossible except by the combination of a number of owners of contiguous properties.

In a recent article* the writer has given some of the figures of cost

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* *Engineering Magazine*, June, 1900.

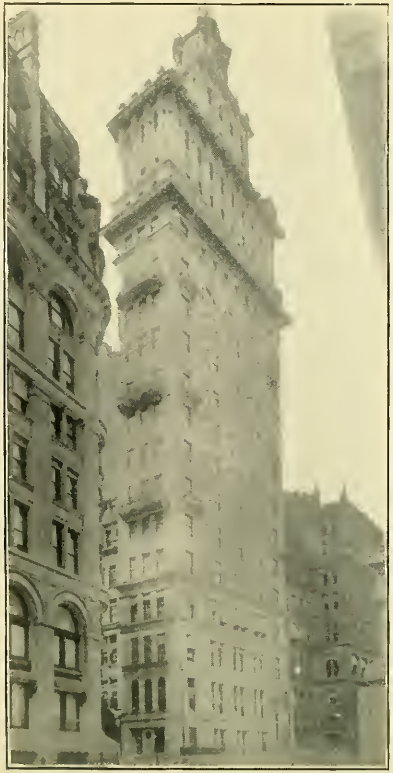

FIG. 1.—MANHATTAN TRUST BUILDING.
NEW YORK CITY.

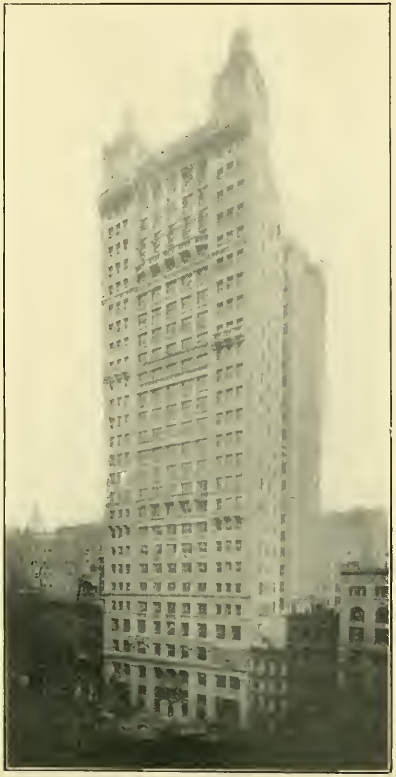

FIG. 2.—SYNDICATE BUILDING, NEW YORK CITY.

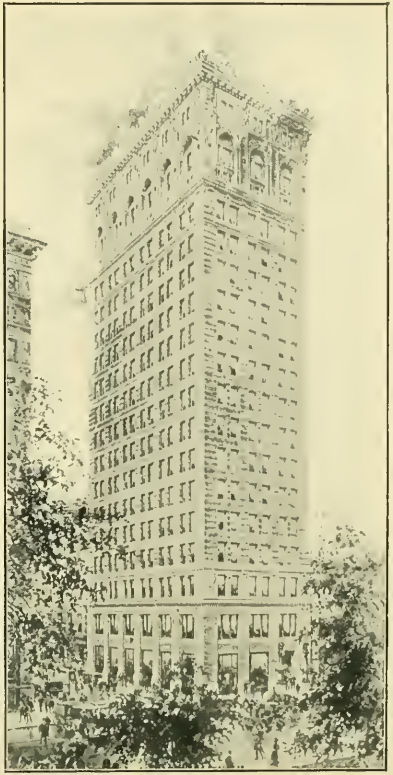

FIG. 3.—BROADWAY CHAMBERS, NEW YORK CITY.

Mr. Bolton.

of internal services, and has shown that the mechanical equipment reaches the proportions of a small central station, and can produce power in several forms under the most economical conditions. The fact that all the waste steam can be utilized for the necessary heating of the building in winter, and for other useful purposes such as heating water and cooking in summer, places these equipments in a position superior to the central station of public supplies.

It is capable of proof that supplies of power in several forms can be sold by such large buildings to neighbors at figures very much less than the present cost of public supplies. Such advantages may thereby be presented to a contiguous property as will of themselves overcome the objection of interference with light or air, and the writer sees no reason why a tall building should not, by such arrangements, be a source of improvement to its older neighbors, and thus directly, as well as indirectly, add to their value.

Vol. XXVI. AUGUST, 1900. No. 6.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS AND DISCUSSIONS.

Note.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

RECENT PRACTICE IN RAILS.

An Informal Discussion at the Annual Convention, July 3d, 1900.*

Subjects for Discussion.

"The Progressive Increase in Weight; the Increase in Hardness, particularly in Carbon; the Sections in most General Use; the effect of changes in Weight, Composition and Section."

By Messrs. Robert W. Hunt and A. L. Colby.

Mr. Hunt. Robert W. Hunt, M. Am. Soc. C. E.—As America came to Great Britain for the rails used on her first railroads, it is perhaps fitting that this paper should be presented to the Society in London, and at its first English meeting.

The facts relating to the introduction of rails into the United States, and, later, their manufacture in that country, are historically recorded, and will only be briefly referred to herein. In obtaining the data, free use has been made of James M. Swank's valuable work, "Iron in All Ages."

The first charter for a railroad in the United States was granted by the Legislature of New Jersey in 1815, but the road was never built. In April, 1823, the New York Legislature granted a charter to the Delaware and Hudson Canal Company to construct a canal and railroad for

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*The discussion of this subject, for which no formal paper was presented, is printed in *Proceedings* in order that the views expressed may be brought before all members of the Society for further discussion. (See rules for publication, *Proceedings*, Vol. xxv, p. 71.)

A number of discussions on this subject, presented at the Convention, were not received in time to permit of preparing them for this number of *Proceedings*. They will appear in a subsequent number.

Communications on this subject received prior to September 22d, 1900, will be printed in a later number of *Proceedings*, and subsequently the whole discussion will be published in *Transactions*.

Mr. Hunt.

the transportation of coal from the anthracite coal fields of Pennsylvania to the Hudson River. The road was 16 miles long, but was not completed until 1829. It was on this road that the first locomotive was run in America.

On Saturday, August 8th, 1829, the "Stourbridge Lion," built in England, and weighing 6 tons, made its first trip; but its active life was short, as it was found to be too heavy for the superstructure of the road.

The first American-built engine was operated on the Baltimore and Ohio Railroad, in August, 1830. It was named "Tom Thumb," and was designed and constructed by Peter Cooper, who was somewhat restricted as to materials, as he had to use gun barrels for tubes. The whole machine weighed but 1 ton, and burned anthracite coal. The experiment was successful, and, based on it, later machines were designed and built; the first one of practical size and use being the "Best Friend of Charleston," which was constructed at the West Point Foundry, in New York City, for the Charleston and Hamburg Railroad of South Carolina. It went into active and successful use on that road in December, 1830.

Only some five years intervened between the opening of the first railroad in the world intended for general freight and passenger service—the Stockton and Darlington—September, 1825; and that of the first one in the United States for the same purposes—the Baltimore and Ohio. Its construction was begun on July 4th, 1828, and "cars were put upon it for the accommodation of the officers and to gratify the curious by a ride," in 1829; but it was not formally opened for travel until May 24th, 1830. It was then 13 miles long, extending from Baltimore to Ellicott's Mills, Md.

Thus, in railroad building, as in many other things, the Americans were early disposed to follow closely after their English relatives; and perhaps, like other younger people, were soon not satisfied to follow, but aspired to lead. Thus, the next passenger railroad to be constructed was the Charleston and Hamburg, already mentioned. This was opened for public use in December, 1830. In September, 1833, it was completed for a distance of 135 miles, and was "the longest continuous line of railroad in the world."

The nucleus, from which later came the great New York Central and Hudson River Railroad System, was the Mohawk and Hudson Railroad, chartered by the New York Legislature in 1826, but not begun until 1830, and opened for travel in 1831. It extended from Albany to Schenectady, 17 miles.

There were some earlier railroads, or more properly tramways, built in the United States, but those named were the first really commercial roads.

The rails used on these roads were of wood with flat bar-iron nailed

Mr. Hunt. to their upper surface. The track of the Baltimore and Ohio Railroad is described as consisting of—

> "Cedar cross-pieces, and of string-pieces of yellow pine from 12 to 24 ft. long and 6 ins. square, and slightly beveled at the top of the upper side for the flange of the wheels, which at that time was on the outside. On these string-pieces iron rails were placed, and securely nailed down with wrought-iron nails 4 ins. long. After several miles of this description of road had been made, long granite slabs were substituted for the cedar cross-pieces and the yellow pine stringers."
>
> "The iron used for rails was ½ to ⅝ in. thick by 2½ to 4½ ins. wide. The heads of the nails or spikes holding it down were countersunk in it."

One would judge, from the varying thicknesses and widths, that the specification and inspection were not very rigid.

Notwithstanding these strap-rails being "securely nailed down," it was found that traffic would loosen them, with the final result of their turning up as the wheels passed over them, and forming what were called "snake heads." These would occasionally tear through the bottoms of the cars, and cause more or less inconvenience if not danger to the passengers. So the American engineers again turned to England, where the same difficulties had led to the invention of rails of different sections. It is believed that the first one was the fish-bellied rail, invented by John Birkinshaw, of the Beddington Iron Works, and patented in October, 1820. This rail was held in cast-iron chairs by side keys or wedges. The Baltimore and Ohio Company soon afterward imported some of these rails.

The Stockton and Darlington, and its follower, the Liverpool and Manchester, which was opened in September, 1830, were principally laid with rails of the Birkinshaw type. The Stockton and Darlington also had a few cast-iron fish-bellied rails.

The Clarence rail was another English invention and was considered an improvement on the Birkinshaw. Rails of that pattern were imported into America for the Allegheny Portage Railroad, built by the State of Pennsylvania over the Allegheny Mountains to connect the canals on either side of them. This road was opened in 1833.

In 1834 the Columbia and Philadelphia Railroad was opened. Part of this road was laid with flat rails, but on the greater part the Clarence rails were used. On both roads the rails rested on stone blocks. These roads were in after years absorbed by the Pennsylvania Railroad.

Another English section was the H-rail, which rested in a chair. These were imported, and used on some of the roads. Still later, came the U-rail, known in Wales as the Evans patent, and believed to have been first rolled at the Dowlais Works.

Some of the flat strap-rails were made in America, but all the sectioned ones were imported. Some attempts were made to use American cast-iron rails, but with unsatisfactory results. It was not until

Mr. Hunt.

1844 that the manufacture of sectioned wrought-iron rails was begun in America. A rolling mill was built in 1843 by the Mount Savage Rolling Mill Co., at Mount Savage, Allegheny County, Md., expressly to make rails. Operations commenced in 1844, and for their first rail, which was of the U-section, they were awarded a silver medal by the Franklin Institute of Philadelphia. The rail weighed 42 lbs. per yard. About 500 tons were laid in 1844 on the road then being built between Mount Savage and Cumberland, Md. A short time later they rolled some 52-lb. rails for a road between Fall River and Boston, and in 1845 and 1846 they rolled T-rails. This mill, after being long abandoned, was finally dismantled in 1875.

The T-rail was generally known in Europe as the "Vignoles" rail, after Charles V. Vignoles, an English railroad engineer, who introduced its use there. But it was really invented by Robert L. Stevens, of Hoboken, N. J., President and Engineer of the Camden and Amboy Railroad.

In 1845, the Montour rolling mill, at Danville, Pa., was built expressly to roll T-rails, and in October of that year there was rolled in that mill the first rail of that section made in America.

In 1846, T-rails were rolled by the Boston Iron Works, Boston, Mass.; by Cooper and Hewitt's mill at Trenton, N. J.; by the New England Iron Company, Providence, R. I.; by the Phœnix Rolling Mill Company, Phœnixville, Pa.; by the Great Western Iron Company, Bradys Bend, Pa.; and by the Lackawanna Iron Works, Scranton, Pa.

In the following years the manufacture was taken up by other companies; but owing to the commercial conditions caused by the severity of foreign competition, early in 1850, only two out of the fifteen rail mills in the United States remained in operation.

These early rails were all short; none over 15 ft. long. As the difficulties of manufacture were overcome and the science of track laying progressed, the length was gradually increased until 21 ft. was reached, and was considered the limit. It was not until about 1859 that railway engineers would accept those of greater length.

The first 30-ft. rails rolled in America were made by the Cambria Iron Company, Johnstown, Pa., in 1855; but they could not find sale for them and they were finally used by that company in their mill yards. The first 30-ft. rails to fill an order were rolled by the Montour Company, in January, 1859, for the Sunbury and Erie Railroad Company.

The rolling of iron rails was attended with many difficulties. If the pile of bars was not heated to a sufficiently high degree, the welds would not be perfect; and if heated too highly, the iron would crack in the process of rolling and yield an imperfect product. If the metal was too soft, although the rail might be free from flaws and bad welds, Mr. Hunt. it would wear out rapidly under traffic. Under all circumstances it was important that the rolling process should be completed as quickly as possible so that the reductions should be made while the iron had lost little of its heat. This, together with some local conditions, led to the invention by John Fritz, Hon. M. Am. Soc. C. E., of the three-high rail train. Three-high sets of rolls had been used for many years in making merchant bars, but it required the application of the "Fritz Yielding Hanging Guides and Driven Feed Rollers," to make them practical for rail rolling. This improvement was put into successful operation at the Cambria Mills in 1857. It has ever since remained as the typical American rail mill. Since the introduction of steel rails there have been several two-high reversing mills on the English plan, used in America; in fact, two of this kind are now running. But the three-high is the American mill, and has permitted the tremendous production which has been attained in later years.

The early mills required the work of handling the material as it passed through the rolls to be done by manual labor, through the use of tongs and hooks. Probably the rolling of iron piles with their necessarily peculiar handling, would have indefinitely continued this, but with the use of solid steel blooms, the troubles lessened and made possible the introduction of automatic machinery. The tong and hook system necessitated the employment of 15 to 17 men, and the production of steel rails was limited to not over 250 tons per turn. Automatic machinery revolutionized this, both as to number of men employed and the possibilities of production.

It was the writer's fortune to introduce the first driven rail-mill tables, those in the works of the Albany and Rennselaer Iron and Steel Company, Troy, N. Y., in March, 1884. These were in front of the finishing rolls, and worked so well that an automatic arrangement was soon after placed in front of the roughing rolls. This latter arrangement was more particularly designed by Mr. Max M. Suppes, then the master mechanic of the works, and now the general manager of the Lorain Steel Company, Lorain, Ohio. Naturally, these devices were protected by letters patent. From this start other inventions were made, and many improvements by other American engineers have followed, until the present American rail mill, capable of turning out 50 000 tons of finished rails per month, has been developed.

It was the writer's fortune to become connected with rail making in 1856, and among his earliest recollections is the statement that the users of rails had in service certain makes which had been and were giving results impossible to be obtained from any of more recent manufacture. How familiar that statement must sound to many of you, and as of recent date!

Then, as now, the question demanded an answer, and many sought for the solution.

Mr. Hunt.

The first iron rails were made from straight puddled bars. These bars were about 1 in. thick and were placed one upon another, until a pile of sufficient weight and height was formed; the pile was then reheated and rolled into rails. And it was to the formation of that pile that inventive genius was applied.

From an investigation of the fracture of some of the rails which had given satisfaction, it was discovered that the pile of bars from which they had been rolled, had been entered in the rolls edgewise, thus bringing the line of welds between the bars in a vertical instead of horizontal position. This presented a different structure to the wheel wear, and seemed to be logical. Based on that supposition many rails were so rolled, and the writer believes that the scheme was patented.

Where the rail was rolled with the layers of the pile in a horizontal position, particular attention was given to the character of the top bar, which would, of course, form the wearing surface of the rail. Cold-short or granular iron was used for it, while the remainder, or at least the flange of the rail, was of fibrous iron.

At one time a rail with a puddled-steel head—or rather with the top bar of the pile of puddled steel—found much favor, but, owing to the difficulty of obtaining uniformly good welds, the results were not satisfactory. Some of these so-called steel-headed rails had the top bar of what was known as silicon steel.

Another plan, on which much money was spent, was to hammer a puddled ball, or weld two puddled balls together, under a steam hammer, and draw them into a slab 2 to 2½ ins. thick, which was used on the top of the rail pile. Under an order from the Pennsylvania Railroad Company, the Cambria Iron Company, in whose employ the writer was then serving, erected a special steam hammer, and made several thousand tons of such rails. Their service was somewhat disappointing, and the practice was abandoned.

At that time, as since, commercial conditions controlled. The railroads had the worn-out rails on their hands, and, regardless of whether or not the practice would give satisfactory results, they adopted a system of having the old rails re-rolled into new ones. At first a certain percentage of new iron was specified, but as the necessities for immediate economies increased, that demand was eliminated from the contracts, and the new rails were composed entirely of the old ones. The best practice was to make a pile of old rails, break it down into bars, which were piled upon each other, and then rolled into rails. But presently this was found to be too expensive to successfully meet the cry for cheaper rails, and only the top and bottom of the piles were formed from re-worked iron, the center being composed of from three to six pieces of old rails.

From the many re-workings, the cheapening of the process of manufacture, and the increasing demands of traffic, the wear of the

Mr. Hunt. iron rails become more and more unsatisfactory, until it seemed as though, from that cause alone, the limit of railway development had been reached. Such situations frequently occur in earthly affairs; and seldom if ever has the occasion failed to be met by a solution of its difficulties. In this case, came the invention of Bessemer.

It is a historical fact that the first rail ever made from Bessemer steel was placed on the Midland Railroad, of England, early in 1857, at a point where iron rails had sometimes to be renewed within three months; and it remained there until June, 1873, some sixteen years, during which time about 1 250 000 trains and any number of detached engines and tenders passed over it.

We all realize that without such an innovation as Bessemer's, the subsequent tremendous expansion on railway development would have been physically impossible.

Railway managers were timid about using steel rails, and in America many attemps were made to produce a satisfactory rail having an iron base and web, with a steel-capped top. None was satisfactory, and the Bessemer steel rail soon conquered the situation.

The first steel rails laid down by an American railroad were imported by J. Edgar Thomson, President of the Pennsylvania System.

The first to be manufactured in America were rolled at the mills of the North Chicago Rolling Mill Company, Chicago, Ill., on May 24th, 1865, from ingots produced in experimental steel works at Wyandotte, Mich. They were not many in number, and were made on the regular iron rail rolls of the mill. Several of the rails were put in local railway tracks and gave good service.

The first production of steel rails in the United States, on a commercial order, was at the Cambria Iron Company's mill, in August, 1867, from ingots made by the Pennsylvania Steel Company, near Harrisburg, Pa. The converting works of that company were completed some time in advance of its rail mill, which led to an arrangement under which the ingots were sent to Johnstown to be hammered into blooms which were then reheated and rolled into rails. The steel was made under the management of the late Alexander L. Holley, M. Am. Soc. C. E., then in charge of the Pennsylvania Steel Company. George Fritz was the Chief Engineer and General Superintendent of the Cambria Iron Company, and Alexander Hamilton, Superintendent of the rail and other mills, while the writer was in direct charge of the steel department.

It is a matter of some interest, that the ingots were drawn down by the steam hammer which had been installed some years before to make the hammered iron slabs for the Pennsylvania Railroad Company's rails. From this time, the production in America of Bessemer steel rails increased rapidly.

Mr. Hunt.

For a time after the starting of the Pennsylvania Steel Company's Bessemer Works, the ingots were cast from the top, on the then-accepted English plan. Mr. Holley's mind was not so constituted that he could long follow any beaten track without an effort to do better work on some other line. Thus, he introduced the bottom-casting of ingots; pouring the steel into a central octagonal mould about 14 ins. diameter at the bottom and 10 ins. at the top, from the bottom of which the metal flowed through connecting gates into four surrounding moulds 8½ ins. square. This plan was adopted after consultations with Mr. George Fritz, who had rolls turned to take the 8½-in. ingots. The central or sprue ingots were hammered into blooms. It was found that the small ingots rolled satisfactorily, while, on the contrary, the central ones cracked badly during working.

This led to much discussion and consultation among the operative officers of the Cambria Company and Mr. Holley, the result of which was that John E. Fry, then superintendent of the Cambria Iron Company's iron foundry, suggested the use of a rammed-up center sprue, 4 ins. in diameter, connecting through fire-brick gates with surrounding ingots; the sprue and gates to be treated as scrap. This plan answered admirably.

While in charge of the experimental Bessemer Works at Wyandotte, Mich., in the interest of the Cambria Iron Company, the writer had developed a manner of bottom-casting ingots. Mr. Holley, having protected his plan by a patent, Mr. Fry and the writer united in patenting theirs, and their interests and those of Holley were consolidated. For some years after this, practically all bottom-casting of ingots in America was licensed under these patents. After a time the price of rails became so much reduced that the loss incident to the scrap of the center sprue and bottom gates made in bottom-casting became a serious matter, and while it was and is impossible to cast as sound, and hence as good, ingots from the top, the better plan was abandoned.

At first, all the American Bessemer's works pursued the English plan of reducing the ingots to blooms under steam hammers. This was so at the Pennsylvania and Troy Works. The success in rolling the 8½-in. ingots at Johnstown led to the invention of the American blooming mill, and this soon completely superseded the steam hammer in rail making.

This idea originated with Mr. George Fritz. Holley and he were intimate friends and exchanged views freely. Holley had severed his connection with the Pennsylvania Steel Company, and returned to the Troy, N. Y., Works. There he built a three-high blooming mill. While it had tables, their rollers were not power-driven, and the ingots had to be pushed into the rolls and turned over on the tables by hand. Soon after, George Fritz built a blooming mill at Johns-

Mr. Hunt. town, in connection with a Bessemer converting plant, and put into use his patented ideas of driven rollers, hydraulically controlled movable rolls, and a "turning over and sliding from pass to pass" device, christened by the mill hands a "go-devil," which permitted the economical handling of larger ingots. This was the birth of the American blooming mill. In perfecting his plans George Fritz had the benefit of the advice of his brother John, then manager of the Bethlehem, Pa., Works.

Perhaps these details apply more to rolling-mill practice than to the rails themselves; but the writer thinks that they have played a most important part in relation to the character of steel rails, and are pertinent to the subject. Holley started the innovation by which the production of steel ingots has been increased so greatly. Fritz gave the blooming mill, which would not only take care of all that was sent to it from the converting works, but like Oliver Twist, ask for more; and the late Capt. William R. Jones, Robert Forsyth, M. Am. Soc. C. E., and several others built rail mills which were not satisfied with the amount of steel sent to them by any blooming mill. This has all been magnificent. It has made possible undreamed-of low prices for steel rails. It has helped to build railroads, but has it improved the quality of the rails produced?

Steel rails, when first manufactured, replaced iron rails, which, through their deteriorated quality and the increased duty demanded of them, were giving most unsatisfactory service. Some of the early steel rails failed, but most of them were so much better than the best of their predecessors that such failures did not excite adverse comment. They were of what would now be considered light sections, and thus in their production from the 6 × 6-in. or 7 × 7-in. blooms from which they had been rolled, had received much work, and at a comparatively low temperature. In the writer's judgment the greatest factors in the production of good rails are covered by the words "work and temperature." All steel men know that work at high heats does not change the grain of steel at all in proportion to work given at lower temperatures.

For years after the introduction of steel rails a 65-lb. per yard section was considered a heavy one. In fact, in America it was the heaviest used, and much the largest percentage was not over 60 lbs. These were rolled from 7 × 7-in. blooms. The ingots from which the blooms were made were generally 12 × 12 ins. After the bloom was formed it was examined carefully after becoming cold, and all cracks and mechanical imperfections were chipped out. Then, after slow heating, with care to avoid too high a temperature, the blooms were rolled into rails by light reductions. While this was being done, if a defect showed itself, the process was stopped until it was chipped out. Now, this slow work at a moderate and steadily decreasing temperature, resulted in a fine grained metal, which, of necessity, no matter what may have been its chemical composition, would give greater resistance to the wear of traffic than could be possible from the coarser grained steel which is in the head of the heavier and more rapidly rolled sections of to-day. Mr. Hunt.

By waiting long enough the things of the past always become the best. That is, provided the past is not examined too closely. It must be remembered that the early rails replaced a much inferior article; in fact, created a revolution in railway maintenance of way. Hence, if a few from any cause failed, it excited little comment; they were quietly replaced by others. After a while these failures were forgotten, and the whole lot of existing rails was instanced as an example of what rails should be. Another thing which must not be overlooked is, that the early steel rails had the ultimate stress of traffic applied by slow degrees. In other words, the traffic to which they were subjected when first put in service was for them light duty. Heavier rolling stock, faster and more frequent trains, came gradually. The old-time rails, which are in these later days so reverently mentioned, had been subjected to a cold-rolling process before being given their severest task. To-day an 80-lb. rail is hardly cold before a 175 000-lb. locomotive, hauling 100 000-lb. capacity cars at 35 miles per hour; and limited expresses of heavy Pullmans at 60 miles per hour are thundering over it.

The details of manufacture of steel rails changed, not only in America, but also in England and other countries. This had to be, and it would to-day be as impossible to return to the earlier methods as to restore the service of stage coaches.

In 1876, the writer presented a paper at the Philadelphia meeting of the American Institute of Mining Engineers, on "The History of the Bessemer Process in America," and with great pride chronicled the fact that the North Chicago Bessemer Works, under the management of Robert Forsyth, had, in a single month, produced 6 457 gross tons of ingots, and that it led the world's records. These ingots were all rolled into rails. To-day, the North Chicago Converting Works and rail mill are abandoned, their places having been taken by the present South Chicago plant of the Illinois Steel Company, in which rail mill the largest month's production has been 58 103 gross tons of standard-sectioned rails.

The Edgar Thomson Works of the Carnegie Steel Company has made 47 074 gross tons of rails in a calendar month. Other American mills are turning out a large tonnage, but it is believed that the foregoing at present hold the record.

While the faster work of modern practice has somewhat altered the character of the steel in rails, it must not be assumed that the product has been increased without any regard to other considerations.

Mr. Hunt. That is not true; on the contrary, the outward character or finish of the rails has been improved to a radical extent. While working fast, the improved machinery is also reliable, and the care exercised in keeping true to section, square sawing, accurate drilling and straightening of both line and surface, yield results which it would have been impossible to obtain in the earlier days. In fact, the requirements of the railways, in consequence of increased weight and speed of traffic, etc., have made it imperative that such finished rails should be given them.

It is not desired to draw any invidious comparisons, but, in the writer's judgment, American makers are to-day not only turning out the most rails, but at the same time the best finished ones now produced. Moreover, foreign rails, imported into the United States and Canada during late years, have not worn any better than American rails.

It has been stated that examining into the past sometimes disproves assumptions. So that, while in the earlier days rail steel and rails were made with all the time and care which has been described, all the rails produced were not satisfactory. In fact, the experience of the Pennsylvania Railroad was such that their chemist, Charles B. Dudley, M. Am. Soc. C. E., made an elaborate investigation into the chemical composition of their satisfactory and unsatisfactory rails. His deductions were presented to the American Institute of Mining Engineers in October, 1878, and elicited a memorable discussion. Dr. Dudley concluded that rail steel could be too hard for good service, even though the rails did not actually break. His conclusions were in favor of chemically softer metal. Some of those discussing the matter thought and stated that the size of the rail sections should not be ignored.

As the accredited authority of the great Pennsylvania Railroad, Dr. Dudley's views carried added weight, and it resulted in a demand in America for softer rails. The writer thinks that no one to-day will attempt a defence of that position. In fact, the practice did not long prevail. But it cannot be safely claimed that the present rails, whether made in America or imported from Europe, are giving absolutely satisfactory results. They are permitting the accomplishment of work which, but a little while ago, would have been considered an impossibility. Still, if engineers had ever been absolutely satisfied with that which was, progress would have halted. Heavy-sectioned rails which will yield better results than those now being obtained are needed. Our railway organizations have generally become so situated financially, that they need no longer be limited to the immediate present in the policies of their administrations.

In the old countries, railroads were built because there was a population whose needs demanded them. In this country, they were often built because there was a tremendous amount of country and no population. This led to cheap construction, but while we still have plenty Mr. Hunt. of room for more people, our country has become rich enough to justify the best of railroads, and, in fact, imperatively demands them. The successful operation of the roads themselves can be only on such a basis. As the railroads increased in number, and their requirements varied in accordance with their traffic and profiles, and being constructed and operated by many different men, it was natural that not only the weight of rails used, but their sections, should differ. In fact, almost every road had its own particular section. The variations between many were slight, but sufficient to necessitate the use of special rolls in their manufacture. This had become so pronounced, and caused so great an investment of capital on the part of rail makers and loss of time in changing from one section to another, etc., that Mr. Holley, in his characteristic progressive spirit, attacked the situation in a paper presented to the American Institute of Mining Engineers, in February, 1881. In this he stated that, answering his inquiries, the eleven Bessemer mills then making rails in the United States had sent him drawings of 188 patterns which were considered standard ones, and that 119 patterns of 27 different weights per yard were regularly manufactured. Mr. Holley gave drawings of many of these and pointed out the absurdity of some of the variations. His paper attracted wide interest, but it was a difficult matter to reach. However, its discussion was continued by others later. Mr. P. H. Dudley, who had devoted much time to the study of the wear of rails, and who invented a recording car for the examination of the rails, contributed papers on the subject to both the scientific press and societies. Mr. Hawks, M. Am. Soc. C. E., then Chief Engineer of the Michigan Central Railroad, advocated certain sections, as also did D. J. Whittemore, Past-President Am. Soc. C. E., and the writer also presented a series of sections in a paper read before the American Institute of Mining Engineers, February, 1899.

This Society appointed the committee on "The Proper Relation to Each Other of the Sections of Railway Wheels and Rails," which performed its duties in a thorough manner; and following and resulting from its reports, the Society appointed a committee to consider and recommend a series of Standard Rail Sections. This was in 1891, but the final report of the Committee was not made until June, 1893.* During the intervening years the members of the committee had worked faithfully; consulted personally and by correspondence with many of the chief engineers of the railroad systems of the country, and agreed upon all points but one. One member, Mr. George S. Morison, differed with the Chairman, Mr. G. Bouscaren, and with Messrs. Foster Crowell, Virgil G. Bogue, S. M. Felton, J. D. Hawks, E. T. D. Myers, Samuel Rea, Thomas Rodd, A. M. Wellington, F. M.

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* *Transactions*, Am. Soc. C. E., Vol. xxviii.

Mr. Hunt. Wilder, and Robert W. Hunt, as to the width of heads of the proposed sections, and, on that point, made a minority report.

As secretary of the committee during the latter part of its work, the writer knows the difficulties and labors of the task, and naturally, is gratified to know that the recommended rail sections are to-day practically the standard ones for American railroads. During 1899, quite 75% of all the rails rolled by American rail mills were of what are commercially known as the American Society sections.

Geographical and commercial conditions must govern. When the Bessemer process was first introduced in America, imported English pig irons were used in making the steel. American irons were experimented with and gradually displaced foreign irons. This practice first prevailed in the works located west of the Allegheny Mountains. They soon relied entirely upon charcoal pig, made from Lake Superior and Missouri ores. This was much higher in phosphorus than the English irons, but the results obtained from it were so satisfactory that the investigation continued and extended to the use of American mineral fuel irons, both anthracite and coke. After a time these completely displaced both foreign coke and American charcoal brands, in both western and eastern works.

It happened that, while the most available western ores contained percentages of phosphorus fully up to the limit possible for Bessemer uses, the cheapest eastern ores were quite low in that obnoxious element. Hence, it has been and is a fact, that some of the rail makers located east of the Alleghenies can produce rails low in phosphorus contents, while using the lowest priced pig metal. The opposite is true of the western mills. These geographical and commercial conditions have led to the use of entirely distinct chemical specifications in the two districts—at least by some of the leading makers in those districts.

The heavier equipments and higher speeds required more rigid road beds, which could only be obtained by heavier sectioned rails. These were gradually adopted. It was naturally expected that as the sections were increased so would the resulting amount of service yielded by the rails. From the very first, the results obtained were disappointing, and the writer doubts whether we will ever succeed in getting results as satisfactory as those yielded by the lighter sections. As the area of the section is increased, so, of necessity, will the work upon the steel in forming it be decreased; and as the resulting mass is enlarged, so will the amount of heat retained in it at the time of the final reduction through the rolls be increased. In the writer's judgment it will be found that the most satisfactory results will be obtained by so modifying the rolling system that the final pass (or better, passes) shall be given after the temperature of the partially formed rail has been lowered. This is not by any means a new idea, but as yet it has not been carried out in a manner calculated to obtain the best results.

Mr. Hunt. Some years ago, Mr. F. A. Delano, now Superintendent of Motive Power of the Chicago, Burlington and Quincy Railroad, in the interest of that company, had some rails rolled at the South Works of the present Illinois Steel Company, then owned by the North Chicago Rolling Mill Company, on such lines and under his personal supervision. Unfortunately, these rails were of a peculiar section, which was not continued, but the writer believes that the wear of the metal itself was encouraging.

The satisfactory wear being given by rails renewed by the "McKenna Process" at the Joliet and Kansas City Mills of the McKenna Steel Working Company, bears very strongly on this point. Mr. McKenna takes rails which have become unfit for further service in main line tracks, from having become rough in surface, through flow of metal, or other causes; or which have become curve-worn on the side of the head; and, after carefully removing any fins which have been formed on the upper edges of the heads by metal flow, charges them into a long furnace, and, when heated to not more than 1 500° Fahr., they are drawn from the furnace by a mechanical contrivance which at the same time removes any scale which may have formed on their surface, and slightly upsets or flattens the section. The rail is then passed through a set of forming rolls, from which it is carried forward to another set, in which it is given a finishing pass. The rail is then sawed hot, and cold-straightened and drilled in the usual manner. And while the section has been somewhat reduced, the original finishing sections and heights have been maintained.

Now, the steel has been given finishing work at low temperature, and examination has proven that the grain of the metal in the head of the rails has been "fined." But, more important than all, the wear of the renewed rails is promising to be much more satisfactory than that obtained from new rails of heavier sections. This treatment of rails is no longer in an experimental state, as it is over five years old, and there are nearly 100 000 tons of renewed rails in service on the Chicago, Milwaukee and St. Paul; Atchison, Topeka and Santa Fé; Wabash and other large systems. One chief engineer, on whose road there are many of these rails, says: "No rail ought to be used at all until after it has been renewed."

The writer has already stated that, owing to geographical, and hence commercial, conditions the chemical specifications under which rails are made differ east and west of the Allegheny Mountains. In the Scranton and Bethlehem District what are known as the New York Central and Hudson River Railroad specifications, which were originally formulated for that road by Mr. P. H. Dudley, are regarded as the standard; while for the mills west of the Alleghenies, a different formula is followed. Some of the main railway systems insist on buying under their own chemical specifications, no matter where made.

Mr. Hunt. The writer has gone on record so often, as believing that in the absence of work at low heats, incident to the present method of making heavy-sectioned rails, it is important to increase the carbon with the section to as great an extent as the phosphorus present will permit, without incurring risk from breakage, that it seems unnecessary to repeat the arguments.

At the Atlanta meeting of the American Institute of Mining Engineers, in October, 1895, the writer presented a set of specifications for "Steel rails of Heavy Sections Manufactured West of the Alleghenies." In accordance with these specifications thousands of tons have been made and used with satisfactory results. During the last two years the western makers have declined to limit the phosphorus to less than 0.10 %, but, in fact, have been making steel with a fraction less than that amount—say 0.09 to 0.096 per cent. And he regrets to say that in many cases they insist that the amount of carbon shall be less than that which he has advocated. He believes, however, that gradually, higher carbon will prevail; and certainly has not had any cause to change his mind on the subject. His experience as a steel-rail maker, and as an observer of the wear of steel rails of many sections and diverse chemical composition, leads him to advocate: *First*, work, after careful heating of the steel, and continued until its temperature has been much reduced. *Second*, that the carbon percentages shall be increased in proportion to the increase of rail section, the ultimate amount being, of necessity, limited by the contained percentage of phosphorus. In all cases he advocates the use of drop tests, on samples from each heat of steel.

At present many of the American railway engineers use the drop test, but none of them demands the static or tensile tests insisted upon by so many engineers of other countries; nor does the writer think there is any necessity for these latter. The chemical analyses and drop tests are all sufficient.

As a matter of record, the writer gives the chemical formulas contained in his specifications of 1895, in accordance with which, as stated, thousands of tons of rails have been made and have given good results. And while at present the western makers decline to limit their steel to 0.085% phosphorus, the writer certainly sees no reason to decrease the carbon. In other words, so many rails have been made and proven safe with quite as much carbon as given in these specifications, and with 0.10% phosphorus, that the writer does not think the former element should be made less, certainly not until the details of manufacture have been changed.

The standard specifications of the Louisville and Nashville Railroad Company are also given, as they cover both Bessemer and basic open-hearth steel rails.

The so-called New York Central and Hudson River Railroad Company's specifications are also appended; and the present standard specifications of the western rail mills. Mr. Hunt.

ROBERT W. HUNT'S SPECIFICATIONS.

SEC. 8.—The carbon in the 70-lb. section shall not be below 0.43% nor over 0.51 per cent. In the 75-lb. section, not less than 0.45% nor over 0.53 per cent. In the 80-lb. section, not less than 0.48%, nor over 0.56 per cent. In the 90-lb. section, not less than 0.55%, nor over 0.63 per cent. In the 100-lb. section, not less than 0.62%, nor over 0.70 per cent.

The phosphorus shall not exceed 0.085 per cent.

The silicon shall not be below 0.10 per cent.

The remainder of the chemical composition of the steel to be left to the maker's judgment.

LOUISVILLE & NASHVILLE RAILROAD SPECIFICATIONS.

The steel used for rails shall contain carbon as follows: For 58¼-lb. steel rail from 0.42 to 0.52 of 1%; for 70-lb. steel rail 0.47 to 0.57 of 1%, and for 80-lb. steel rail 0.55 to 0.65 of 1%, and not more than 0.085 of 1% of phosphorus, or 0.07 of 1% of sulphur. Silicon, 0.15 to 0.20 of 1 per cent.

When the steel used for the rails has been made by the basic open-hearth process, it should be of the following chemical composition: For 58¼-lb. steel rail, from 0.45 to 0.52% of carbon; for 70-lb. rail, 0.50 to 0.57%; for 75-lb. rail, 0.55 to 0.60%; for 80-lb. rail, 0.62 to 0.67 per cent. The steel used for all rails shall contain silicon from 0.10 to 0.20%, 0.15% being preferred; manganese, 0.90 to 1%; phosphorus, not to exceed 0.05%; sulphur, not to exceed 0.05 per cent.

NEW YORK CENTRAL & HUDSON RIVER RAILROAD SPECIFICATIONS.

	65-lb.	70-lb.	75-lb.	80-lb.	100-lb.
Carbon	0.45 to 0.55	0.47 to 0.57	0.50 to 0.60	0.55 to 0.60	0.65 to 0.70
Silicon	0.15 to 0.20	0.15 to 0.20	0.15 to 0.20	0.15 to 0.20	0.15 to 0.20
Manganese	1.05 to 1.25	1.05 to 1.25	1.10 to 1.30	1.10 to 1.30	1.20 to 1.40
Sulphur	0.069	0.069	0.069	0.069	0.069
Phosphorus	0.06	0.06	0.06	0.06	0.06
Rails having carbon below will be rejected	0.43	0.45	0.48	0.53	0.60
Rails having carbon above will be rejected	0.57	0.59	0.62	0.65	0.70

SPECIFICATIONS OF THE WESTERN RAIL MILLS.

Section 1.	50-lb. up to 60-lb.	60-lb. up to 70-lb.	70-lb up to 80-lb.	80-lb. up to 90-lb.	90-lb. up to 100-lb.
Carbon	0.35 to 0.45	0.38 to 0.48	0.40 to 0.50	0.43 to 0.53	0.45 to 0.55
Phosphorus	not over 0.10	not over 0.10	not over 0.10	not over 0.10	not over 0.10
Silicon	not over 0.20	not over 0.20	not over 0.20	not over 0.20	not over 0.20
Manganese	0.70 to 1.00	0.70 to 1.00	0.75 to 1.05	0.80 to 1.10	0.80 to 1.10

Mr. Colby. **Albert Ladd Colby**, M. Am. Soc. Mech. Eng. (by letter).—Mr. Hunt very appropriately opens the discussion by remarking that:

"As America came to Great Britain for the rails used on her first railroads, it is perhaps fitting that this paper should be presented to the Society in London, and at its first English meeting."

To this the writer would like to add that as America now exports rails to British Colonies, it is also fitting, perhaps, that at this first English meeting, a few words be addressed to English engineers in friendly criticism of foreign rail specifications, and a few practical suggestions given as to modifications which can safely be made in their specifications without any danger of obtaining an inferior product from American rail mills, and with the decided practical advantages of lower prices and more prompt delivery.

No discourtesy is intended to our hosts, the Institution of Civil Engineers, in this evident effort to advertize American steel. The halls of our technical societies, and the columns of our technical press are just as freely open to our English friends, and no one is quicker to appreciate and adopt foreign ideas, patents or products than the American engineer, and the American purchasing agent.

The following official statistics show the rapid increase in the tonnage and value of steel rails exported from America in recent years:

	Gross tons.	Value.
1894..........................	12 229	$323 880
1895..........................	8 8[illegible]7	222 661
1896..........................	72 503	1 712 716
1897..........................	142 808	2 949 901
1898..........................	291 038	5 787 384
1899..........................	171 272	6 122 382

In the following brief review, the requirements of foreign rail specifications will be compared with those contained in a proposed standard American specification for rails, recently framed by Committee No. 1 of the American Section of the International Association for Testing Materials, and which specification will be presented by this Committee at the Annual Meeting of the American Section, in October, 1900, for discussion and adoption as the standard American specification.

1. The Processes of Manufacture Specified.

In a review of forty-one foreign rail specifications, eight were found which limit the manufacturer to the use of "The best English or Spanish hematite pig iron and charcoal spiegeleisen." This requirement, of course, cannot be complied with in American mills, nor in the present state of the art, does it seem a necessary stipulation in any case, particularly as, if strictly interpreted, it seriously limits competition.

2. The Chemical Properties Specified.

(*a*) *Carbon.*—In 63% of the forty-one foreign specifications reviewed, limits in carbon are specified, and in the majority of these cases a range of carbon of from 0.10 to 0.15% is given. This is in general accord with American practice, except that the proposed American standard specification increases the carbon gradually with the increased weight of section, specifying in each case a range of 0.10 per cent. This is in accord with Mr. Hunt's suggestion that "The carbon percentages shall be increased in proportion to the increase of rail section." Mr. Colby.

The actual percentages of carbon given in foreign specifications will not be discussed in detail. The proper structure to insure safety and wearing qualities is what is desired in rails; and as the percentages of carbon, and other hardening elements which will give this structure, vary with the finishing temperatures, the chemistry must be changed to suit the varying conditions of manufacture. Some American rail mills have recently been successful in experiments looking toward the finishing of rails at a lower temperature than at present in vogue in America, without diminishing the present output. This recently patented improvement is in accord with Mr. Hunt's suggestion that:

> "In the writer's judgment it will be found that the most satisfactory results will be obtained by so modifying the rolling system that the final pass (or better, passes) shall be given after the temperature of the partially formed rail has been lowered."

In short, an international standard composition for rails is utterly impracticable, and it is useless for any country, or any engineer, to assert that their composition is the best, and, therefore, should be adopted in all countries.*

(*b*) *Phosphorus and Sulphur.*—Thirty-two per cent. of the foreign specifications reviewed, called for a phosphorus and sulphur of 0.06% or below. Rails meeting these requirements will be furnished in America, at, of course, a considerably higher price than charged for rails of 0.10% phosphorus, which latter forms by far the largest proportion of the product of American rail mills. Many thousands of tons of American rails of 0.10% phosphorus have given satisfactory service under severe conditions. The increased cost of 0.06 or 0.08% phosphorus rails, over that of rails containing 0.10% phosphorus does not, in the opinion of many competent judges in America, obtain a correspondingly safer or better rail from American mills.

Mr. Hunt states that:

> "Owing to geographical, and hence commercial, conditions the chemical specifications under which rails are made differ east and west of the Allegheny Mountains. In the Scranton and Bethlehem District what are known as the New York Central and Hudson River Railroad specifications, which were originally formulated for that road by Mr.

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* See C. P. Sandberg's paper: "The danger of using too hard steel rails." *Journal, Iron and Steel Institute*, No. 2, 1898, pp. 76-110; especially p. 106.

Mr. Colby. P. H. Dudley, are regarded as the standard; while for mills west of the Alleghenies, a different formla is followed."

The Bethlehem District referred to is no longer a producer of rails, and the writer happens to be in a position to know that the New York Central and Hudson River Railroad Company has very recently abandoned the 0.06% phosphorus limit recommended by Mr. P. H. Dudley, and has purchased rails of 0.10% phosphorous. It can hence be safely asserted, that, as far as tonnage is concerned, practically all American roads now use rails of 0.10% phosphorous.

(*c*) *Silicon and Manganese.* —About one-half of the foreign rail specifications examined mentioned limits in silicon and manganese. The silicon specified varies from 0.06% to 0.25 per cent. The manganese varies between the wide limits of 0.40% and 1.20 per cent. American mills would not be inclined to furnish rails on a specification limiting the manganese to 0.40%, the requirement mentioned in one specification examined. The American standard specification for rails states that silicon shall not exceed 0.20%; and gives a range of 0.30% in manganese, the limits varying with the increased section between 0.70 and 1.10 per cent.

In general, it may be stated that the strict adherence, by a foreign engineer, to a specified complete chemical composition, independent of the varying conditions of manufacture, and the rejection of large lots of rails solely because the sample, assumed to represent the lot, exceeds in some respects the specified chemistry, compels his client to pay much more than is necessary to obtain a first-class rail to-day from American mills.

3. Samples for Analysis.

Some foreign specifications require that every heat of rail steel shall be analyzed for phosphorus and arsenic, and stipulate that if the phosphorus and arsenic exceed 0 06% the heat is not to be used. It has been proved conclusively that arsenic should not be classed with phosphorus in its effect upon the physical qualities of steel.* Furthermore, as there is no rapid method by which both phosphorus and all of the arsenic can be determined, the ingots of each blow could not be held for analysis, but must be rolled into rails and subsequently rejected if the analysis shows a phosphorus and arsenic of over 0.6 per cent. This burden, with the unnecessarily frequent analysis demanded, will not be assumed by the American manufacturer without substantial remuneration, and will more often result in a refusal to bid unless this requirement of the specification be withdrawn.

Another very arbitrary clause in certain foreign specifications, states that each 500 tons of finished rails will be accepted or rejected on the analysis of a piece of one rail, selected by the engineer; said analysis to be made, at the contractor's expense, by an independent chemist, selected by the engineer. In American mills the rails pass over several cooling beds, and are drilled on many sets of presses. Without great additional labor, therefore, it is impossible to land the finished rails of consecutive heat numbers in 500-ton piles in the yard, to await the complete analysis of the independent and probably distant chemist. In the light of all that has been published, and candidly admitted by the manufacturer, as to the unavoidable variation in composition even of the different parts of a section of rail, to say nothing of the variation of different rails of a blow, how can an engineer conscientiously accept or reject 500 tons of rails from the analysis of a single rail ? Mr. Colby.

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* F. W. Harbord and A. E. Tucker, *Journal, Iron and Steel Institute*, No. 1, 1888, pp. 183-196, and No. 1, 1895, pp. 131-132 and 127-128.
J. E. Stead, *Journal, Iron and Steel Institute*, No. 1, 1895, pp. 77-140.

4. The Physical Properties Specified.

(*d*) *Tensile Strength and Elongation.*—With a specified chemical composition, a drop test, and, in most cases, a dead-weight test also, tensile strength and elongation is an unnecessary requirement. In fact, when carbon, and other hardening elements are specified, and strictly adhered to, the tensile strength and elongation should not also be made the subject of specification. Tensile specimens represent, at best, only a small part of the cross-section of the rail. If taken from the center of the head, the results are affected by the segregation of the hardening elements, and do not represent the portion of the metal subjected to greatest strains in service; if taken from the exterior surface, the results are apt to be affected by the presence of a few partly welded blow holes. In neither case, therefore, can the tensile specimen be considered as fully representing the rail from which it was cut, much less any lot of rails from which the sample was selected.

(e) Drop Tests Specified.—All the foreign specifications reviewed, very properly contain a drop test; some of the drop tests specified, however, are open to considerable criticism. Where chemical composition is specified, and faithfully followed, the drop tests should not include a certain maximum deflection, but should simply specify that the piece of rail shall not break under a single blow on the head, the tup falling from a height increasing with the weight of the rail section. Where the engineer prefers to include a certain maximum deflection in the drop test, besides specifying that the piece of tested rail shall not fracture, the percentage of carbon should be omitted from the chemical requirements. Either method will insure a safe hard rail; but a specified range of 0.10% in carbon is perhaps a better and more prompt means of securing and maintaining uniformity in the product.

(f) Dead-Weight Tests Specified.—This transverse test under static load should include a determination of the yield point, and, by means of still heavier loads beyond the yield point, the determination of

Mr. Colby. greatest permanent deflection. The test may be looked upon as unnecessary when the chemical composition is fully specified and when the ability of the finished rails to withstand shock is determined by a drop test. However, the requirements of the dead-weight tests contained in foreign specifications are met without difficulty by American mills. Seventy per cent. of the forty-one specifications examined specify a dead-weight test, but in quite a number only a weight is used which will give no permanent set. The test is, therefore, frequently regarded in American mills as at least unnecessary, for, when the loads specified are within the elastic limit of the steel, the deflections are merely factors of the section of the rail.

5. Finish.

Some foreign specifications require, even after the templets have been approved by the engineer, resident abroad, that a section of the rail 12 ins. long must be submitted to the foreign engineer and approved in writing before the general rolling can proceed. This is a needless delay, as confidence can be safely placed in the skill and integrity of American manufacturers.

In a number of foreign specifications the permissible variations in height of sections are too rigidly drawn to allow for the unavoidable wear of the rolls. Smoothness of track is in nowise jeopardized by an allowance of $\frac{1}{64}$ in. under and $\frac{1}{32}$ in. over the specified height; they are the variations permitted by the best American railroads. A number of foreign specifications allow a less variation in length of rail than $\frac{1}{4}$ in., which is the uniform practice of American railroads.

Most foreign specifications allow a variation in weight of 1% for individual rails. This can be easily reduced to 0.50% for the entire order, but the rails should be paid for on actual, and not estimated, weights.

6. Inspection.

American mills are noted for their willingness to afford the inspector every facility to enable him to satisfy himself that the rails are being furnished in accordance with the specifications. In return, they have a right to expect from a foreign purchaser inspection which will not delay manufacturing operations. This is by no means always realized, and, as it is a frequent cause of expensive and annoying delays, it is a proper subject of comment.

The inspectors sent to American mills are frequently unfamiliar with rail inspection, and are, therefore, too strict in their inspection, and too slow in their decisions. Again, when the specifications require all four sides of every rail to be examined for flaws, all holes gauged, each rail tested for length and squared on each end, and stamped in four places by the inspector's mark, and also require him to be present at the testing, to weigh 1% of the rails, and to watch the loading of Mr. Colby. the rails to see that only those bearing his stamp are loaded, it is manifestly unfair to the manufacturer to send but one inspector to the mill and expect the manufacturer to conform his product to the number of rails that one inspector can pass upon, in nine or ten hours of the twenty-four. Lack of inspectors frequently necessitates a change of rolls at the mills, and has delayed the departure of vessels on which the rails were being loaded. Assuredly, a sufficient number of inspectors to inspect the entire product of the mill each day should be furnished.

Some foreign specifications require that all rejected rails shall be piled up and kept until the completion of the contract, so that, at any time, the inspector may check them with the numbers entered in the book; and that no rejected rail shall be sold or broken until the completion of the contract. This is manifestly unfair to the manufacturer, because on a large contract, not continuously rolled, a considerable tonnage of second-quality rails might be tied up, which might otherwise be sold. Some foreign specifications state that the final acceptance of the rails and splice bars shall be at the port of delivery. This is unreasonable; final acceptance should be based on tests and inspection made at the place of manufacture.

The writer is confident that foreign purchasers have no desire to knowingly include in their specifications, requirements which, while securing no more efficient product, operate to limit competition and increase the cost of inspection and the price of product. This thought prompted the foregoing criticism of foreign rail specifications, which, it is hoped, will result to the mutual advantage of the foreign customer, and the American mills.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS AND DISCUSSIONS.

Note.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

FILTRATION OF WATER FOR PUBLIC USE.

An Informal Discussion at the Annual Convention, July 3d and 5th, 1900.*

Subject for Discussion.

"The several Processes now used for the Removal of Objectionable Matter; their Comparative Sanitary Effect, Cost and Reliability."

By Messrs. Rudolph Hering, Philip H. Palmer and E. Perrett.

Mr. Hering

Rudolph Hering, M. Am. Soc. C. E.—When continually growing centers of population reach a point when their water supplies can no longer be obtained from springs or wells, it becomes necessary to utilize larger sources, such as rivers. Open streams, however, are often turbid and polluted, at least by the surface washing of rain water, and it becomes desirable to purify such water before use. Thus originated the practice of filtering public water supplies, and it is interesting to many of us to know that, within a few miles of where we are now gathered, the first large filters for this purpose were constructed by Mr. James Simpson, one of the former presidents of the Institution, in the year 1829, for the Chelsea Water Company.

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* The discussion of this subject, for which no formal paper was presented, is printed in *Proceedings* in order that the views expressed may be brought before all members of the Society for further discussion. (See rules for publication, *Proceedings*, Vol. xxv, p. 71.)

A number of discussions on this subject, presented at the Convention, were not received in time to permit of preparing them for this number of *Proceedings*. They will appear in a subsequent number.

Communications on this subject received prior to September 22d, 1900, will be printed in a later number of *Proceedings*, and subsequently the whole discussion will be published in *Transactions*.

In the early days the aim was to get a clear and palatable water. Mr. Hering. Since the discovery of the bacterial origin of many diseases, and the further discovery that such pathogenic bacteria may be introduced into our bodies through the use of water, a further and most important requisite is the elimination of disease germs also.

Filtration has, therefore, a triple duty to perform: It must render the water healthful, clear and pleasant to taste.

As might be expected, different lines of practice have been followed in different countries, and even in the same country, in the endeavor to obtain the most effective and most economical means of water purification. The result has been the development of several distinct processes.

At the last international gathering of engineers interested in this subject, during the World's Fair at Chicago, in 1893, the results of studies pursued at the experiment station of the Massachusetts State Board of Health, were made known to the world. These results contributed much to the knowledge of removing bacterial germs from water, and elevated the practice of filtration from an empirical to a scientific basis.

Since then, further substantial progress has been made on both sides of the Atlantic, but particularly through the extensive experiments made on a large scale at Louisville, Cincinnati and Pittsburg, which covered the conditions of water highly charged with suspended matter as well as polluted by sewage. These experiments included also a test of filters of another order than those previously investigated in Massachusetts.

Experience has not yet brought about a general agreement regarding the relative merits of these several filters and methods of purification now in use. It was hoped, therefore, that a discussion at this second international gathering of engineers might contribute greater clearness as to the controlling elements, and thus lead to a more rapid progress toward the desired end.

We may divide the methods of water purification now practiced substantially into two classes: One requires a large bed of fine sand through which the water is allowed to percolate, at the rate of, roughly, from 5 to 10 cu. ft. per day, or 1 sq. ft. of filter surface, or, a column 2½ to 5 ins. in depth, per hour. The other, with a much smaller bed of sand or similar material, requires from, say, 200 to 400 cu. ft. per day to pass through 1 sq. ft. of filter surface, or, a column of water of from 8 to 16 ft. in depth per hour, which is, on the average, a rate 40 times faster than in the first case.

As the chief difference is this rate of speed, the two systems have been called, respectively, slow and rapid filtration. The appliances have also been called "sand" and "mechanical" filters, because sand is the chief element in the first case, while mechanical contrivances

Mr. Hering. form the chief element in the latter case. They have also been distinguished, respectively, as the English and American filters, from the countries where they were first developed.

For filtering public water supplies, there are still other appliances, of which the Fischer or Worms system and the Maignen system have been most prominent.

The Worms system requires the use of artificial tiles, through which the water is made to percolate. Experience, however, has shown that with a reasonably large yield of water the purity may be insufficient, or *vice versa*, the expense being rather great for any other than originally clear waters.

The Maignen system requires the use of asbestos pulp, which is caused to gradually form a layer or cover over the sand beds of slow filters and collect the sediment and bacteria. It is claimed that it greatly increases the safe rate of filtration per square foot. The cleansing is effected by simply rolling up this cover, which separates readily from the sand. With this contrivance no experience on a large scale has yet been had.

The slow or sand filters have been used almost exclusively in Europe. The principle upon which they act is a double one: First, there is a straining action, in keeping out of the passing water all coarse suspended matter and many of the bacteria, by the slimy sediment layer which forms upon the surface of the sand; and secondly, there is a further disappearance of the bacteria caused by an organic process going on while the water is percolating through the sand.

The efficiency of such a filter depends upon a number of conditions, the most important of which are:

1. *The Size of the Sand Grains.*—It is found that fine sand of uniform size, several feet in depth, gives the best results. It is further found that the number of bacteria in the effluent water increases with a decreasing thickness of sand bed and with an increasing size of sand grains.

2. *The Rate of Filtration.*—A rate of from 2 000 000 to 3 000 000 U. S. galls. per acre per day, or a column of water about 3 to 4½ ins. in depth per hour, is found most satisfactory, as a rule. The number of bacteria passing through the filter increases rapidly with the rate, which should, in any case, be kept uniform to get the best results, and to accomplish which requires the use of controlling devices.

3. *Drainage.*—The free withdrawal of the water from the underdrains, to secure the same rate in all parts of the filter.

4. *Temperature.*—The temperature of the water should not vary greatly, because it controls the pressure required to effect a given rate of filtration, and because the bacterial efficiency decreases with the temperature.

Mr. Hering.

5. *The Age of the Filter Bed.*—New or freshly scraped filter beds give higher numbers of bacteria in the effluent water than old and well-compacted sand layers.

The slow system of filtration has been practiced according to two methods, the continuous and the intermittent. When the amount of dissolved oxygen contained in the water is sufficient for the necessary bacterial action, the continuous method is preferable, because it is simpler and cheaper. It is, therefore, the more common one. When the water is highly polluted, requiring a large amount of oxygen for the proper bacterial action, the intermittent system may be preferable, as in Lawrence, Mass., where the sand beds must be given a frequent aeration, and thereby receive a new supply of oxygen; or, when the water is highly polluted, a double continuous filtration may be practiced, as in several cities of Holland. Still another variation is practiced in Altona, where the first filtrate coming from the filter just after it has been cleaned, and therefore generally not sufficiently pure, is passed through another filter, which has not been recently cleaned, before it enters the city's mains.

In climates where water freezes frequently during the winter, and to a depth of at least several inches, it is customary to cover the filters in order to obtain the best results. Where it is impracticable to do so, as was the case in Hamburgh, special allowance must be made for the decreased bacterial activity in the colder water, and for the mechanical difficulties resulting from the ice.

When the water to be filtered has a high degree of turbidity, economy demands that it be allowed to deposit most of its suspended matter before it is run upon the filters. Settling basins are therefore a necessary adjunct to almost all filters for river water. When this contains finely divided clay, the particles of which are smaller than bacteria, it is necessary to add a coagulant to the water before it enters the settling basins. Unless there is a prior removal of this fine clay, the filter may allow the water to pass through without giving it a thorough clarification.

One day's settling is usually sufficient for the purpose, as by far the largest proportion of suspended matter, and all the coarser matter is removed within that period. While the custom to provide for about one day's settling prevails in America and Germany, it has been preferred in England to build storage reservoirs sufficient in size to hold water for a much longer period. The idea being that, for economical reasons, enough water should be stored for use during the time when a storm makes the river water very turbid.

A slow filter is cleaned by removing a thin layer of sand, ½ to 1 in. in thickness. This upper layer contains not only the suspended matter deposited from the water, but also most of the bacteria.

The second class of filters, the so-called rapid or mechanical filters, Mr. Hering. were first introduced in America, and are extensively used there. They act on the principle of straining, by which the suspended matter and the bacteria are kept substantially on the surface of the filter material. The rapid rate of the passing water does not allow of much organic action below the surface, and requires also a rather coarse filtering material.

In order to hold back the fine matter held in suspension, such as clay particles and bacteria, coagulating substances are added to the water in definite quantities, depending chiefly upon the amount of lime and organic matter contained in the raw water. The resulting flocculent matter settles upon the surface of the filter bed, and then acts chiefly as a strainer, sufficiently fine to hold back the minute particles, including a percentage of bacteria, which under favorable conditions, may be as large as that removed by the slow filters.

Through the investigations chiefly of George W. Fuller, M. Am. Soc. C. E., the conditions for the successful operation of such filters are understood now much better than formerly. It is possible, now, to arrange their operation, so that, from a water of a given quality, fairly definite results can be obtained. The efficiency depends mainly upon the size and character of the grains, upon the rate of filtration, the constancy of this rate, the proper admixture of the necessary coagulants varying with the quality of the water, and upon the arrangements for properly withdrawing the filtered water.

Two kinds of rapid or mechanical filters have been used, those acting under the slight pressure of the water contained in an open filter, and those acting under a high pressure in a closed filter. Although it is in many cases convenient and economical, the high-pressure filter cannot give equally good bacterial results, because the delicate film of coagulant may be more readily ruptured. High-pressure filters, therefore, should be used only for waters which are not seriously polluted.

A rapid filter is cleaned by reversing the current and washing the entire mass of sand thoroughly with filtered water, for which numerous and more or less efficient mechanical devices have been used. This washing process requires from 3 to 5% of the filtered water, and an opportunity of disposing of the waste water in an unobjectionable manner.

In case the water is very turbid a preliminary settling is of advantage also with this class of filters.

From the foregoing necessarily very brief review of the chief characteristics of the two principal methods of filtration now in use, it will be gathered that they may both satisfactorily purify water under many ordinary conditions.

The criteria which should guide in the selection of one or the other method for a particular case are their relative sanitary effects under expected conditions, the reliability of their operation, and their cost. Mr. Hering.

In these introductory remarks it is not the purpose to enter fully and in detail into a comparison of the merits and demerits of the several methods. It is hoped that those who join in the discussion may do so. The speaker will merely state his own conclusions derived from his practice.

The sanitary effect of a filtered water will be judged by the prevailing death and sick rates. We have abundant evidence that a well constructed and faithfully operated filter of the slow type can materially reduce typhoid fever and diarrhœal diseases. There is hardly a question that it will also remove the contagion of cholera. A similarly strong statement regarding the sanitary effect of rapid filters can, from lack of experience, hardly yet be made, though we know that the bacterial efficiency of both classes of filters can be made almost equally high, the slow filters being probably slightly more efficient.

As to the reliability of operation, it seems to the speaker that the slow filters should be given the preference. The great difference in the rate of filtration furnishes the reason for this conclusion. When there is a rupture in the coagulated material covering the filter—and such a rupture is likely to be produced by some irregularity—the amount of unpurified water passing through the filter is many times greater than in the case of a slow filter, where such a rupture, even when it does occur, cannot produce as harmful results.

Regarding the other chances of mishaps, they are less serious and may result equally in both cases. The skill necessary to operate the two kinds of filters may also be considered as equal, if the best results are reached.

We may conclude, therefore, that, as regards efficiency and reliability, both methods can render satisfactory service, depending on the special conditions of the raw water, the degree of purity to be obtained and the care exercised in the operation.

If the raw water is highly polluted, slow filtration, or a double filtration, is to be preferred. In other cases, the decision will generally depend upon the cost.

Regarding the cost, it has been found that often the two methods are about equally expensive. The required investment is usually greater for slow filters, but the cost of operation is correspondingly less, and *vice versa*.

We may expect, therefore, that both the slow and rapid filters will be used in the future with good results in their respective spheres, and that the peculiar conditions of each locality will enable the engineer to decide as to which will give the greater satisfaction at the lower cost.

Mr. Palmer. PHILIP H. PALMER,* M. Inst. C. E. (by letter).—Ten years ago the writer was induced to try Polarite for the filtration of drinking water. Up to that time he had used the ordinary filter bed, made with a 12-in. layer of fine sand, a 12-in. layer of coarse sand, a 9-in. layer of fine shingle, and coarser material, making a total thickness of 4 ft. The rate of filtration varied, according to the state of the bed, from 470 galls. per square yard per 24 hours up as to much as 650 galls.

The drinking water supplied to Hastings is derived from deep wells, and is highly charged with oxide of iron, both in suspension and solution. This is brought out, on contact with the air, and forms a fairly thick deposit of oxide of iron on the surface of the filter bed. The writer tried an experiment with Polarite with very good results; a small filter bed was made with 6 ins. of coarse-grained sand and 12 ins. of Polarite underneath it. The rate of filtration was increased enormously, and the quality of the water after filtration was as good as when filtered at a slower rate. He then constructed at some of the filter beds a large receiving chamber having a screen between it and the distributing channels to the filter beds filled with Polarite. These screens were about 4 ft. high, and the space between them was 2 ft. wide. The water, after being discharged into the receiving basin, passed through the Polarite before being turned upon the ordinary filter bed. After passing through this material the water was freed of a very large part of the iron in suspension, and analyses showed that a very great improvement had been made in the quality of the water.

All the water supplied to Hastings, amounting to considerably over 1 000 000 galls. a day, is now filtered through Polarite; and at present the writer is erecting a battery of six mechanical filters, each capable of effectually filtering 10 000 galls. per hour. These filters are 9 ft. in height and 6 ft. 6 ins. in diameter. They are made of steel plates, properly riveted and stayed, and can be worked at a pressure of from 5 to 40 or 50 lbs. per square inch. The filtering material is Polarite, and the results are far beyond any which have yet come to the writer's knowledge. A recent analysis of water passed through a similar filter is as follows:

Filters of a similar kind are at work at Southwold, in Essex, and at Leighton Buzzard. The results obtained at the latter place are almost extraordinary. The water there is charged with iron to such an extent as to be very perceptibly inky in taste, but after filtration through Polarite in a mechanical filter, at the rate of 8 000 galls. per hour, this taste is entirely removed. The water, which is very cloudy before filtration, is rendered perfectly clear, and about 90% of the iron is removed.

---

* Water-works Engineer to the Corporation of Hastings.

Mr. Palmer.

	Unfiltered.	Filtered.
Appearance	Turbid.	Clear.
Color	Greenish blue.	Greenish blue.
Smell	None.	None.
Deposit	Appreciable quantity.	None.
Nitrous acid	None.	None.
Poisonous metals	None.	None.
Hardness before boiling	10½° Clark.	11¼° Clark.
" after "	4¾° "	5⅔° "
In grains per gallon.		
Oxygen absorbed from permanganate in 4 minutes	0.008	0.007
Oxygen absorbed from permanganate in 4 hours	0.030	0.029
Total dry residue	22.96	26.04
Color of residue	Brownish.	White.
Behavior of residue on ignition	Blackens markedly, burns off readily.	Darkens very slightly, burns off readily.
Nitric acid	Minute trace.	Trace.
Ammonia	0 0019	0.0000
Albuminoid ammonia	0.0022	0.0022
Iron in solution	0.035	Very minute trace.
Deposit, chiefly oxide of iron	0.98	…

After an experience of ten years in the use of this material, and having experimented and tried other methods of filtration, the writer is of the opinion that it forms one of the best filtering mediums it is possible to obtain. Water can be filtered through it perfectly, and at a rate which is almost impossible with most materials. It can easily be cleaned, and does not appreciably lose its bulk through cleansing.

The following are analyses of water after having been filtered through Polarite:

Appearance	Clear.	Clear.	Clear.	Clear.
Color	Very pale blue.	Pale greenish blue.	Pale bluish	Blue.
Smell	Inodorous.	None.	None.	None.
Deposit	None.	None.	None.	None.
Poisonous metals	None.	…	…	…
Phosphoric acid	Minute trace.	…	…	…
Nitrous acid	None,	…	…	…
Hardness before boiling.	9⅓° Clark.	10½° Clark.	10° Clark.	10° Clark.
Hardness after boiling	5° Clark.	…	…	…
In Grains per gallon.				
Oxygen absorbed from permanganate	…	0.010	0.017	0.009
Total dry residue	27.44	…	…	…
Color of residue	White.	…	…	…
Behavior of residue on ignition	Does not blacken perceptibly.	…	…	…
Chlorine	7.14.	7.14	7.28	7.98
Nitric acid	Trace.	Trace.	Trace.	Minute trace.
Ammonia	0.0000	0.0000	0.0000	0.0000
Albuminoid ammonia	0.0000	0.0023	0.0014	0.0007
Micro-organisms per cubic centimeter.				
Total	5	12	6	12
Liquefying	None.	0	2	0
Coli	None.	0	0	0

Mr. Perrett. E. Perrett, Assoc. M. Inst. C. E. (by letter).—The writer was interested, a few years ago, in the design of some filtering apparatus for a town of 30 000 inhabitants. Six filters were at first supplied, and shortly afterward twelve more of a similar kind were provided, so that their satisfactory performance may be assumed.

The filters were tanks, 5 ft. square, made of cast-iron plates, and were in sets of three. A few inches above the bottom was placed a perforated false bottom, supporting a wire-work frame which carried the filtering material, coarse-grained charcoal about 12 ins. deep. Between the false bottom and the bottom plate of the tank was placed a branched perforated pipe. Above the filtering material was placed a wire gauze drum provided with an outlet pipe for the dirty water and refuse.

When filtering, the water was brought in above the material, and, passing down through it, was filtered and escaped through a suitable outlet.

When cleaning became necessary, or rather, advisable, the outlet was shut off, the dirty-water outlet was opened, and compressed air at a pressure of about 6 lbs. was passed through the perforated pipes and up through the dirty filtering material, thoroughly disturbing it and washing away the dirt through the drum. The water was at times very dirty, but was not impregnated with sewage. The rate of filtration was about 120 galls. per foot per hour. The time occupied in cleaning was about 7 or 8 minutes for each filter every 10 or 12 hours.

When filters capable of dealing readily with muddy water are used, settling tanks can advantageously be dispened with.

The usual rate of filtering through ordinary sand filters is about 3 galls. per foot per hour, the filters being cleaned every 3 weeks. By cleaning every 12 hours a very high rate of filtration is possible, the maximum being maintained.

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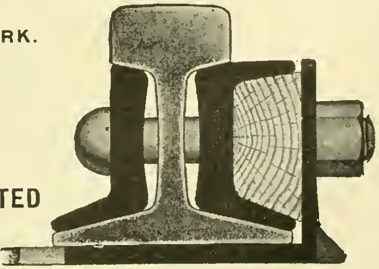

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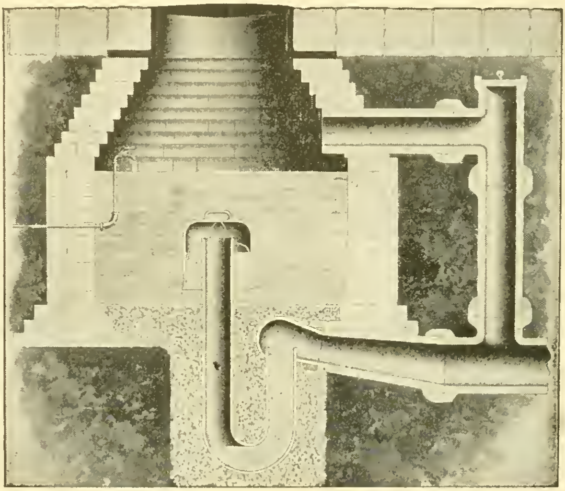

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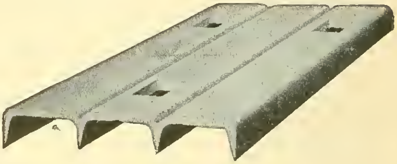

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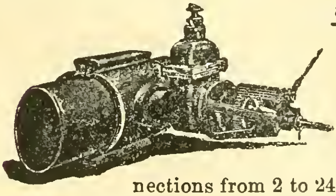

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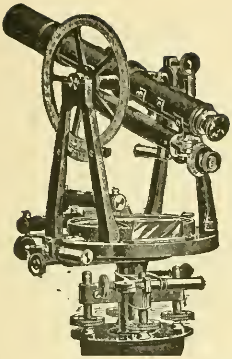

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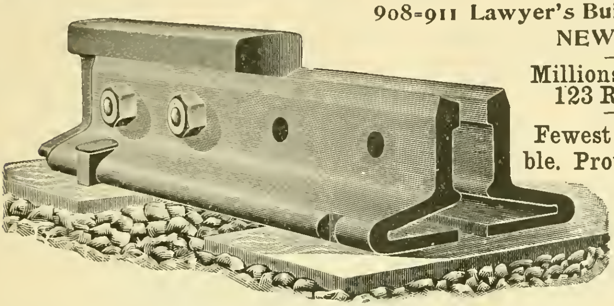

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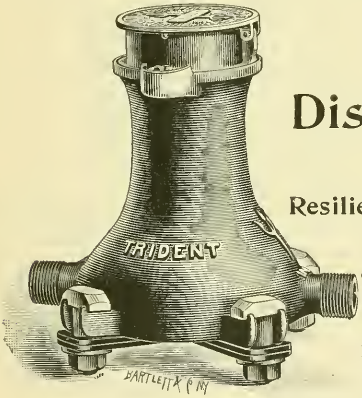

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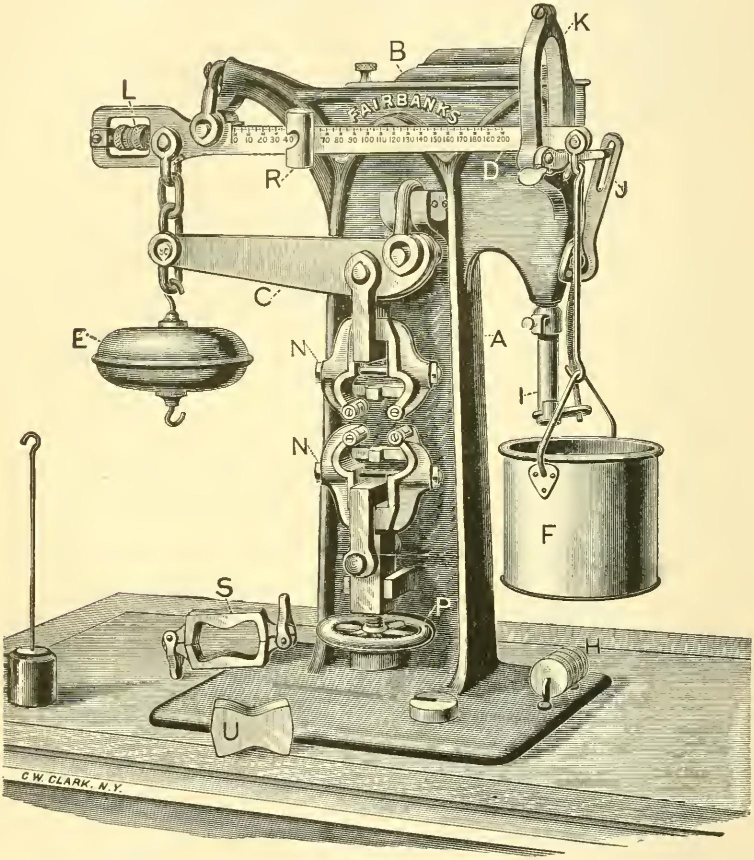

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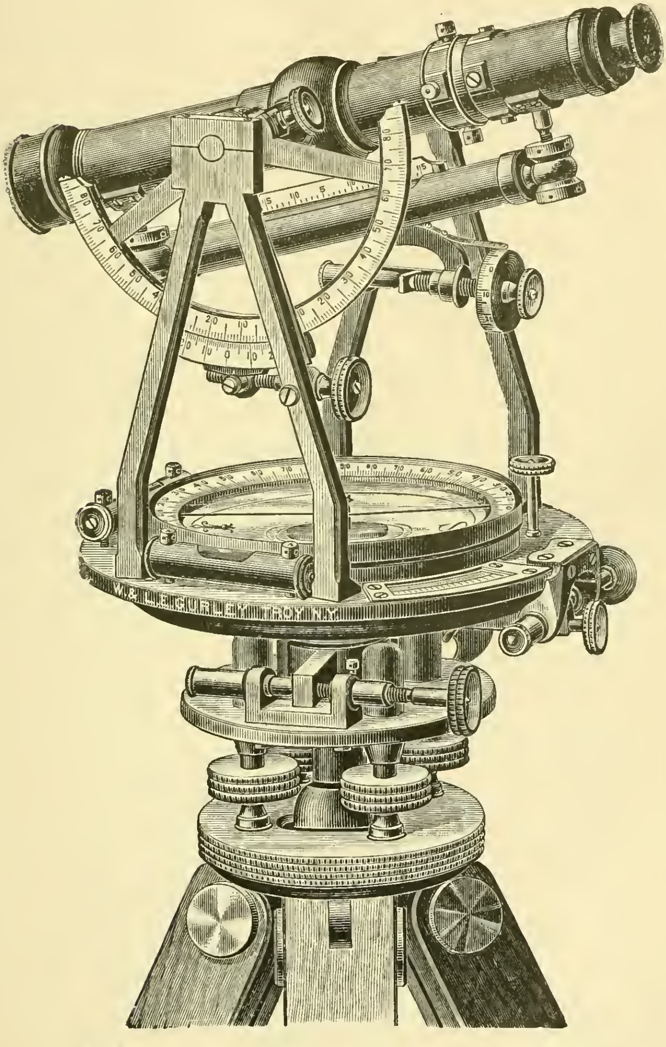
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Vol. XXVI. SEPTEMBER, 1900. No. 7.

PROCEEDINGS
OF THE
AMERICAN SOCIETY OF CIVIL ENGINEERS.

Edited by the Secretary, under the direction of the Committee on Publications.

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REPORT IN FULL OF THE BUSINESS MEETING HELD DURING THE THIRTY-SECOND ANNUAL CONVENTION, AT LONDON, ENGLAND, DURING THE FIRST WEEK IN JULY, 1900.

Meeting Convened.

Thursday, July 5th, 1900.—J. F. Wallace, President, in the chair; Chas. Warren Hunt, Secretary.

The PRESIDENT.—Gentlemen, this is the regular Business Meeting of the American Society of Civil Engineers, as provided for in our Constitution. The first order of business before us is the reading of the minutes of the Society of June 6th, 1900, unless the members desire the minutes to be taken as read.

The minutes were taken as read and confirmed.

The PRESIDENT.—We have some important business before us, which must be transacted. Parliamentary rules, constitutions, by-laws, etc., Election of Nominating Committee.

are devised for the expedition and the proper transaction of the business of associations, but sometimes it is necessary to violate the rules and regulations, or to put constructions on them which may not be strictly technical, in order to prevent the very machinery that you have adopted for carrying on your business from interfering with the carrying out of that business. Our Constitution provides that at these business meetings thirty members shall constitute a quorum. There are not thirty members actually in this room, but there are a great many more than thirty members present at this Convention. Therefore, if there is no objection, we will count as present at this meeting the members who are registered in this building as being in attendance. We must transact the business before us, or the machinery of the Society will be clogged for the next twelve months.

The suspension of the By-Laws was agreed to.

The Secretary read his report on the result of the interrogatory circular, as follows:

NOMINATIONS RECEIVED FOR MEMBERSHIP ON THE NOMINATING COMMITTEE.

"I have the honor to report the result of the interrogatory circular sent to all members of the Society in order to give an opportunity for each to express his preference for the representative of his District on the Nominating Committee to be elected at this meeting.

"*District No. 1.*—Total number of votes received, 72, as follows:

N. P. Lewis, Brooklyn, N. Y.	32
R. S. Buck, New York City	21
Edward P. North, New York City	3
L. L. Buck, New York City	2
William H. Burr, New York City	2
Ira A. Shaler, New York City	2
William Henry Baldwin, Yonkers, N. Y.	1
Theodore Cooper, New York City	1
O. F. Nichols, Brooklyn, N. Y.	1
H. G. Prout, New York City	1
John Thomson, New York City	1
William J. Wilgus, New York City	1
Francis D. Fisher, Cornwall, Ont., Canada	1
Henry Goldmark, Detroit, Mich	1
Chas. Warren Hunt, New York City	1
A. W. Trotter, New York City	1

"The last four gentlemen are ineligible for election on the Nominating Committee, under the Constitution.

"*District No. 2.*—Total number of votes received, 55, as follows:

Fayette S. Curtis, Boston, Mass.	30
Frederic P. Stearns, Boston, Mass.	9
Alexis H. French, Brookline, Mass.	2
S. E. Tinkham, Boston, Mass.	2
Dexter Brackett, Boston, Mass.	1
A. B. Drake, New Bedford, Mass.	1
Richard A. Hale, Lawrence, Mass.	1
William H. Moore, New Haven, Conn.	1

George S. Rice, Boston, Mass.	1
J. P. Snow, Boston, Mass.	1
C. B. Vorce, Hartford, Conn.	1
Desmond FitzGerald, Boston, Mass.	1
George B. Francis, Providence, R. I.	4

"The last two gentlemen are ineligible for election on the Nominating Committee, under the Constitution.

"*District No. 3.*—Total number of votes received, 16, as follows:

E. B. Guthrie, Buffalo, N. Y.	2
William A. Haven, Buffalo, N. Y.	2
Emil Kuichling, Rochester, N. Y.	2
H. Andrews, Albany, N. Y.	1
Edwin A. Fisher, Rochester, N. Y.	1
Charles C. Hopkins, Rome, N. Y.	1
William E. Hoyt, Rochester, N. Y.	1
J. M. Shanly, Joliette, Quebec, Canada	1
J. Nelson Tubbs, Rochester, N. Y.	1
T. McC. Leutzé, Albany, N. Y.	2
Palmer C. Ricketts, Troy, N. Y.	2

"The last two gentlemen are ineligible for election on the Nominating Committee, under the Constitution.

"*District No. 4.*—Total number of votes received, 17, as follows:

L. Y. Schermerhorn, Philadelphia, Pa.	4
A. Bonzano, Philadelphia, Pa.	1
James Christie, Philadelphia, Pa.	1
Mendes Cohen, Baltimore, Md.	1
Bernard R. Green, Washington, D. C.	1
Henry R. Leonard, Philadelphia, Pa.	1
James K. Lyons, Pittsburg, Pa.	1
Edgar Marburg, Philadelphia, Pa.	1
David E. McComb, Washington, D. C.	1
William A. Pratt, Wilmington, Del.	1
Edwin F. Smith, Philadelphia, Pa.	1
Emil Swensson, Pittsburg, Pa.	1
William R. Webster, Philadelphia, Pa.	1
Joseph M. Wilson, Philadelphia, Pa.	1

"*District No. 5.*—Total number of votes received, 29, as follows:

Charles L. Strobel, Chicago, Ill.	10
Onward Bates, Chicago, Ill.	3
Ira O. Baker, Champaign, Ill.	2
George H. Benzenberg, Milwaukee, Wis.	2
William H. Searles, Cleveland, Ohio	2
Lyman E. Cooley, Chicago, Ill.	1
Charles E. Greene, Ann Arbor, Mich.	1
E. A. Handy, Cleveland, Ohio	1
William H. Hughes, Chicago, Ill.	1
Robert W. Hunt, Chicago, Ill.	1
J. B. Johnson, Madison, Wis.	1
George A. Marr, Houghton, Mich.	1
E. H. McHenry, St. Paul, Minn.	1
J. W. Schaub, Chicago, Ill.	1
C. A. Wilson, Cincinnati, Ohio	1

"*District No. 6.*—Total number of votes received, 33, as follows:

J. M. Johnson, Louisville, Ky.	11
Sydney F. Lewis, New Orleans, La.	2

Election of Nominating Committee (continued).

William Starling, New Orleans, La.	2
Channing M. Bolton, Charlottesville, Va.	1
Charles S. Churchill, Roanoke, Va.	1
William H. Courtenay, Louisville, Ky.	1
B. L. Crosby, St. Joseph, Mo.	1
William J. Hardee, New Orleans, La.	1
J. F. Hinckley, St. Louis, Mo.	1
M. L. Holman, St. Louis, Mo.	1
W. B. W. Howe, Spartanburg, S. C.	1
Wynkoop Kiersted, Kansas City, Mo.	1
Hunter McDonald, Nashville, Tenn	1
R. E. McMath, St. Louis, Mo	1
E. T. D. Myers, Richmond, Va	1
A. M. Scott, Charleston, W. Va	1
R. L. Van Sant, St. Louis, Mo	1
J. A. L. Waddell, Kansas City, Mo	1
W. B. Wright, New Orleans, La.	1
Robert Moore, St. Louis, Mo	1
J. A. Ockerson, St. Louis, Mo	1

"The last two gentlemen are ineligible for election on the Nominating Committee, under the Constitution.

"*District No. 7.*—Total number of votes received, 22, as follows:

A. S. Riffle, San Francisco, Cal.	3
A. J. Tullock, Leavenworth, Kans	3
C. E. Grunsky, San Francisco, Cal	2
George H. Mendell, San Francisco, Cal	2
Francis W. Blackford, Butte, Mont	1
William G. Curtis, San Francisco, Cal	1
E. B. Cushing, Houston, Tex.	1
J. Herron, Telluride, Colo.	1
W. H. Kennedy, Portland, Ore.	1
C. D. Marx, Palo Alto, Cal.	1
George T. Prince, Omaha, Neb.	1
H. C. Ripley, Galveston, Tex.	1
D. W. Ross, Boise, Idaho.	1
B. S. Wathen, Dallas, Tex.	1
George A. Quinlan, Houston, Tex.	1
Hiram N. Savage, National City, Cal.	1

"The last two gentlemen are ineligible for election on the Nominating Committee, under the Constitution.

"Respectfully submitted,
"CHAS. WARREN HUNT,
"*Secretary.*"

NEW YORK,
JUNE 13TH, 1900.

The SECRETARY.—The first names on the list for District No. 1 are those of Mr. N. P. Lewis and Mr. R. S. Buck, Mr. Lewis having 32 votes and Mr. Buck 21.

The PRESIDENT.—Mr. Lewis and Mr. Buck have the two highest numbers of votes, and I should be glad to have a motion on the subject.

J. A. OCKERSON, M. Am. Soc. C. E.—I move that Mr. N. P. Lewis be elected for the First District.

The motion was seconded, which was agreed to, 19 voting for and none against.

The President.—In District No. 2 Mr. Curtis, of Boston, has 30 votes, which is the highest number.

Henry Manley, M. Am. Soc. C. E.—Mr. Curtis is a representative of the New York & New Haven Railroad, and Mr. Francis, the present member of the Nominating Committee, is also an employee, in an indirect way, of that road. We in Boston had an idea that that would be a little too much of New York & New Haven on that committee, and we have voted for Mr. Stearns. I, therefore, move that Mr. Frederic P. Stearns be elected member of the Committee from District No. 2.

The President.—I think that, owing to the fact that Mr. Curtis received such a large number of votes, both these names ought to come before the meeting, and, therefore, I will put Mr. Curtis' name first.

On Mr. Curtis' name being put, 8 voted for.

On Mr. Stearns' name being put to the meeting, 12 voted for.

The President.—Mr. Stearns is elected a member of the Nominating Committee for District No. 2.

The President.—For District No. 3 there are three names that have received the highest number in the ballot, and I think we should confine the names to one of those three.

C. E. Goad, M. Am. Soc. C. E.—Will it be in order for me to propose Mr. Guthrie?

The President.—Yes.

The motion for the election of Mr. E. B. Guthrie was put, and carried unanimously.

The President.—In District No. 4 Mr. Schermerhorn, of Philadelphia, has the highest number of informal votes.

A Member.—I beg to move the election of Mr. Edgar Marburg as member of the Nominating Committee.

The motion was seconded.

The President.—As the ballot is simply informal, it seems to me that Mr. Marburg, who has attended our Convention, and takes a great interest in the Society's welfare, is the proper man to be elected.

Mr. E. Marburg was unanimously elected.

The President.—In District No. 5 the gentlemen receiving the highest number of votes are Mr. C. L. Strobel and Mr. Bates, of Chicago.

A Member —I move that the informal ballot for Mr. Strobel be confirmed.

The President.—We cannot do that, but we can entertain a motion for his election.

A Member.—Then I will nominate for election Mr. Charles L. Strobel.

Election of Nominating Committee (continued).

Mr. Strobel was unanimously elected.

Mr. Ockerson.—I am instructed by my associates in St. Louis to nominate Mr. Edward Flad to represent District No. 6.

The President.—There are 11 votes in favor of Mr. Johnson. Of course, this is entirely informal, but on account of the number of votes in favor of Mr. Johnson I feel it my duty to put the names of Mr. Johnson and Mr. Flad both before you. I will, therefore, put the name of Mr. Johnson first.

There being no votes in favor of Mr. Johnson, the President put the name of Mr. Flad, and he was unanimously elected.

A Member.—I will move the nomination of Mr. A. J. Tullock to represent District No. 7.

The motion was seconded, and carried unanimously.

The President.—We would like to know how many Corporate Members entitled to vote there are in this room, simply for the purpose of our records.

A show of hands was taken of the Members and Associate Members, and it was found there were just thirty present.

The President.—I have the pleasure to announce that I will take back the remarks I made at the first part of the meeting, as there is a quorum now present.

The Secretary read the following report of the ballot for suggestions as to the Time and Place of the Annual Convention of 1901:

VOTES RECEIVED IN REGARD TO TIME AND PLACE FOR HOLDING THE ANNUAL CONVENTION OF 1901.

Time and Place of next Convention.

"I have the honor to report the result of the letter-ballot asking for suggestions as to the time and place for holding the Thirty-third Annual Convention of the American Society of Civil Engineers.

"The total number of ballots received was 180, the result being as follows:

"For Place for holding Convention:

Buffalo, N. Y.	42	Denver, Colo.	4
Chicago, Ill.	10	Niagara Falls, N. Y.	4
Cleveland, Ohio	10	Pittsburg, Pa.	4
New York City and vicinity	9	Atlantic City, N. J.	3
Boston, Mass.	8	Cincinnati, Ohio	3
St. Louis, Mo.	7	Mackinac Island	3
Washington, D. C.	7	Steamer between Buffalo and Duluth	3
Duluth, Minn.	5	Vicinity of Lake Champlain	3
New Orleans, La.	5		

"Eleven places received two votes each, as follows:

Asheville, N. C.
Bar Harbor, Me.
Detroit, Mich.
Mexico.
Old Point Comfort, Va.
Philadelphia, Pa.
Richmond, Va.
St. Paul, Minn.
Salt Lake City, Utah.
Saratoga, N. Y.
Sault Ste. Marie, Mich.

" Twenty-eight places received one vote each, as follows:

Alexandria Bay, N. Y.
Albany, N. Y.
Baltimore, Md.
Birmingham, Ala.
Chautauqua, N. Y.
Colorado Springs, Colo.
Gulf of Mexico (some point on).
Halifax, Canada.
Hotel Wentworth, New Castle, N. H.
Hot Springs, New Mexico.
Jacksonville, Fla.
Long Branch, N. J.
Los Angeles, Cal.
Maine Woods.
Milwaukee, Wis.
Narragansett, R. I.
Newport, R. I.
Omaha, Neb.
Porto Rico.
San Francisco, Cal.
Savannah, Ga.
Seattle, Wash.
Tampa, Fla.
Thousand Islands, N. Y.
Toronto, Canada.
United States.
White Mountains, N. H.
Yellowstone National Park, Wyo.

" The vote on Time for holding the Convention, omitting suggestions as to particular parts of months, resulted as follows:

4 suggest the month of February.
1 " " " March.
2 " " " April.
8 " " " May.
82 " " " June.
44 suggest the month of July.
9 " " " August.
8 " " " September.
2 " " " October.

" Respectfully submitted,
" CHAS. WARREN HUNT,
" *Secretary.*"

NEW YORK,
JUNE 13TH, 1900.

The PRESIDENT.—This report, gentlemen, is for your information, but I understand it is usually the province of the Board of Direction to actually settle the place of holding the Annual Convention, and the appropriate procedure is, to move that this matter be referred to the Board of Direction.

Mr. Ockerson moved that the matter be referred to the Board of Direction, with power to act. (Carried.)

Mr. OCKERSON.—In that connection, I have received this morning a communication from St. Louis, which reads as follows:

"*Resolved*, That the members of St. Louis present at the Annual Convention be requested to notify the Society that we hope to have a World's Fair in St. Louis in 1903, and desire, in that case, to have the American Society meet there on that date."

I move that the matter be referred to the Board of Direction. (Carried.)

Proposed Amendments to the Constitution.

The SECRETARY.—The following proposed Amendments to the Constitution, having been received by the Secretary under the provisions of Article 9 of the Constitution, were sent some time ago to each member of the Society. They come up for discussion at this meeting, and this meeting determines whether they shall be voted upon by the Society with or without amendment. The amendment reads as follows:

Proposed Amendments to the Constitution (continued).

"Amend Art. VII, as follows:

"SECTION 2. Strike out this section and substitute the following:

"2. At the Annual Meeting of each year, seven Corporate Members, not officers of the Society, one from each of the geographical districts, shall be appointed by the meeting to serve for two years; who, with the five living last Past-Presidents of the Society, shall be a committee to nominate officers for the Society.

"The Board of Direction may prescribe the mode of procedure for appointing this Committee.

"The Committee so appointed shall meet at the Annual Convention of the Society, and nominate candidates to fill the offices, named in Article V, so as to provide, with the officers holding over, a Vice-President and six Directors residing in District No. 1, and twelve Directors divided equally, with regard to number and residence, among the remaining districts, Nos. 2, 3, 4, 5, 6 and 7.

"A list of nominees for the offices to be filled at the next Annual Election shall be presented by the Committee to the Board of Direction within ten days after the nominees have been selected."

Mr. OCKERSON.—In order to bring that matter before the Society I move that the amendment be ordered to be considered by the Society. The object of the amendment was to meet the objection that many members living at some distance from New York, find that, under the present methods, they are obliged to go to New York, at a considerable expense, to spend fifteen or twenty minutes in selecting officers of the Society. You will remember that at our last Convention someone proposed that the Society should pay the expenses of these delegates. I hardly think that many members would favor a movement of that kind, but it seems to me altogether proper that they should favor some method that would relieve the members of the extra expenses that seem to many of us unnecessary. The member for St. Louis, for instance, would have to expend at least $100 in money, and perhaps nearly a week in time, to meet the members in New York City, and in about fifteen minutes' time that he devoted to the duty, the officers would be selected. It seems to me that if that could be coupled with the Annual Convention, it would relieve many of the Western members of that extra expense, and would ensure a larger attendance at the meetings of the Nominating Committee.

The PRESIDENT.—For the information of the members present, I will read part of the third section of Article 9, in reference to the amendments.

"Amendments presented to the Secretary not less than sixty days previous to the date of the Annual Convention shall be sent by letter to the several Corporate Members of the Society at least twenty-five days previous to the Annual Convention. Said amendments shall be in order for discussion at the Business Meeting during such Annual Convention, and may be amended in any manner pertinent to the original amendments by a majority vote of the Business Meeting during the Annual Convention, and, if so amended, shall be voted upon by letter-ballot in form as amended by said Business Meeting; if not so amended, they shall be voted upon by letter-ballot as submitted. The vote to be counted at the first regular meeting in October."

I understand that this section of Article 9 has been observed, so far, in relation to this proposed amendment. Have you any further remarks upon it? You understand that the question is simply the submission of this amendment as proposed to the Corporate Members of this Society by letter-ballot.

On the motion being put, it was carried; 28 voting for.

The PRESIDENT.—It is unnecessary to take a negative vote as there are only 30 Corporate Members in the room.

Mr. OCKERSON.—I beg to move—

Resolutions of Thanks.

"That the American Society of Civil Engineers in Convention assembled, sends cordial greeting to the *Société des Ingenieurs Civil de France*, and expresses its hearty thanks for the warm reception accorded to its delegates in Paris."

The resolution was carried unanimously.

RUDOLPH HERING, Vice-President, Am. Soc. C. E.—I beg to move that the President appoint a Committee to draw up an appropriate resolution of thanks to the Institution of Civil Engineers, and the various other corporations that have so generously and liberally entertained us at this Convention.

The motion was seconded and carried with acclamation.

Remarks by the President.

The PRESIDENT.—Before proceeding with the discussion of the subjects assigned for this morning at the close of the Business Meeting, I desire to make a few remarks, particularly for the non-resident members, and not only for those who are actually present with us, but for those who will receive the proceedings of this meeting. The headquarters of our Society, as you all know, is in New York City. The meetings are held twice each month, except during the vacation months of the year, and the burden of the business of the Society naturally falls upon the resident members. Never before, during my connection with the Society, have I so thoroughly realized the importance to the Society, and particularly to the non-resident members, of the fact that the members residing in the City of New York, and in the immediate vicinity, give their time and their best thought to the proper conduct of our business. The non-resident members receive the publications, and they occasionally visit New York, and attend some of the meetings; but the work of the New York members, which is gratuitous and generous work, is something I do not think one non-resident member in a hundred thoroughly understands or appreciates. I would particularly call attention to the burdensome duties that rest upon our Secretary, and to the faithfulness, energy, tact and ability which he devotes to carrying on that work. (Hear, hear.)

Another matter I would like to speak to you about is in connection with our publications. For two years, during my period of holding the office of Vice-President, I was a member of the Publication Com-

Remarks by the President (continued).

mittee, and I was surprised at the manner in which some papers are presented. What I am saying now is of course not for general publication, but simply for the members of our Society, and we do not expect this to get into the Press. I am talking as a father to his children.

If some of the papers presented to that Publication Committee by men who stand high in our profession had been presented by pupils in a High School they would never have been permitted to receive consideration. Papers written out in long hand, on both sides of the paper, sheets of different length, underlined, words erased, and matters of that kind, and with a footnote asking the Secretary to please check the mathematical formulas, and, if he found they were not correct, to notify the author, or make them correct.

The papers presented to this Society should come written by a typewriter, and printed on one side of a sheet, and they should come absolutely clean. No other work should be expected of the Secretary and Publication Committee, than the work of criticism in the proper sense. The Publication Committee, or Secretary, should not be expected to furnish grammar, or check mathematical formulas, or anything of that sort. They are, of course, expected to give the papers that character of criticism which all papers need, and the editing which all papers need, even when written by those of us who might be most familiar with the subjects. But they are not expected to go into details and construct the papers themselves. I hope you will pardon me for having taken up so much of your time on this matter, but it is a very important one, and one that has been sadly neglected by our members. That is one reason why papers which come to us written by members are frequently sent back to them, and when they are sent back members take exception to it, when they should be thankful that they are treated as courteously as they are by the Publication Committee.

I also desire to call attention to the fact that one of the thankless offices of this Society is that of the Vice-President. There is a rule that when the President, who, coming from a long distance, can rarely attend the meetings, is absent, the chair is to be taken by the Vice-President. During the time I have nominally occupied the chair it has been actually occupied by one of our Vice-Presidents, who is here, and who has made it his conscientious duty always to find out whether or not the President would be in attendance, and at inconvenience to himself has attended and presided at the meetings. I refer to Mr. Rudolph Hering, whom, in declaring the Business Meeting adjourned, I would like to ask to preside during the remainder of the Convention.

Adjourned.

RECEPTION OF AMERICAN ENGINEERS,

IN THE

LIBRARY OF THE INSTITUTION OF CIVIL ENGINEERS, MONDAY, JULY 2d, 1900.

Address of Welcome by Sir Douglas Fox, President, Inst. C. E.—Responses by John F. Wallace, President, Am. Soc. C. E.; H. S. Haines, M. Am. Soc. C. E., and Jesse M. Smith, Vice-President, Am. Soc. M. E.

Sir Douglas Fox, President, Inst. C. E.—Ladies and Gentlemen:—It is my high privilege as President of the Institution of Civil Engineers to bid you all this day a most hearty welcome. We were very glad when we heard in the spring that a number of our brethren from the other side of the Atlantic—that little pond as you look upon it, which often seems to us a very long distance—were coming over here for the Paris Exhibition; and we hoped they would be kind enough to call on their way and see some of the old folks in the old country. The result of that is that we have the pleasure this afternoon of welcoming you most heartily to the Institution of Civil Engineers, in a building which has many traditions, about which I will say a few words. Before doing so, I should just explain to you that this Institution is the home of the Parent Society of British Engineers. It is cosmopolitan in this sense, that it includes every class of Civilian Engineer, and that is the meaning from our point of view of the words "Civil Engineer." Now, the great advantage of that for you and for us on the Council of this Institution is, that I have this afternoon the honor of being supported on this platform by representatives, not only of my own Council, but of that of the Mechanical Engineers who have been your kind hosts during the last week, of the Electrical Engineers, of the Naval Architects, and of the Iron and Steel Institute. I have only got to mention those names to you to show you that on this occasion I represent a very great force, not only in this country, but throughout the world. There are men here who have made their mark, as there are men on the other side, facing me, who have made a very great mark upon the world; and it is good for us to come and see one another face to face on an occasion like this. Then, on the other hand, because we are cosmopolitan, we have been able to extend our invitation, not merely to the Society of Civil Engineers of America, of which some of us are very proud to be members, but also to members of the other engineering societies, the Mechanical Engineers, the Mining Engineers, the Electrical Engineers, and the Naval

Architects of the United States, and we hope that all those bodies are more or less represented among us this afternoon. There is one face absent that I should very much have liked to have seen here, whose name I must mention to you, and that is our old and honored Secretary for 40 years, now our Honorary Secretary, James Forrest. He has written expressing his great regret that his health does not permit him to be among us, but I felt that any meeting of the Institution of Civil Engineers would not be complete unless reference were made to his honored name. If you look about you will find he is in evidence in several ways, both in this room and in other parts of the Institution.

Now, may I say to you, friends, that we meet on this occasion with a sense of very deep sympathy on account of the news that has just come to us across the Atlantic, and we could not do otherwise than express this to you. We feel deep sympathy with this sad event that has taken place in New York. We have all had a good deal to make us serious during the last year or two. You have had your share of troubles; we have had a great many of our own. But there has been one bright rift in the clouds, at any rate in the view of this nation of ours—a very bright rift through the dark clouds of war—and that has been the sympathy and the hearty fellowship that has been shown by the American nation. That is as it ought to be. If we English-speaking people of the United States, and of the great Empire of Great Britain and our Colonies, only stand together for what is right and true, the whole world cannot prevent the progress that you and I would like to see.

It is one of the advantages, I think, that we men of science and men of industry enjoy, that we can sometimes approach the consideration of these things with a calmer mind, with a more resolute determination to pull together, than is always possible in the political world. We have found this with our neighbors on the Continent. All through the various events of the last few years there has been a most hearty and friendly feeling between the scientists and the engineers of the Continent and those of this country; but that is only a distant feeling compared with what we entertain toward our brethren of America. We look upon you as very strong competitors. Well, we are quite ready for it, and we only hope that we shall be able to learn from you a great deal to teach us how to compete with you in the way which we have to travel in the future. I think it is one of the most pleasant things in connection with this Institution, and I have no doubt it is so in your own, that while on this platform there is hardly one of us who is not a strong competitor with others, we are all on the most intimate terms of friendship with one another, and quite ready to help one another in any difficulty or in any doubt. And so in the same way it is good for us, strong as we must be in competing together, to meet here and to exchange our friendly thoughts, and to cheer one another on in the great problems we have to attack. We have plenty of such to deal with. Some of us will not live to see all their fulfilment; but depend upon it that the engineers of the United States and Great Britain will have a great deal to do with the future of the world, and it is for us to try as far as we can to direct that future rightly in the course of true progress and upright feeling, and of straightforward, honest work.

I want to add a few words to you about this Institution of Civil Engineers. I am afraid I cannot say to you what I may be able to say of Warwick Castle, where I hope a great many of you will meet us, that it is an old building. The room in which we are now is somewhat modern, although the lecture hall is considerably older. There you will shortly be amid old traditions, if you can apply the word old to one of the youngest of the professions. In 1818 this Institution of Civil Engineers was founded, and in 1820 took more definite shape under the Presidency of Thomas Telford. I feel especially proud to-day for one among other reasons, which is that when I came into this room I occupied the original chair in which Thomas Telford used to preside. Nothing could make an engineer feel prouder than that. Founded in 1818, this Institution has witnessed the birth and growth of our profession. Before that time there were men mighty in their isolated strength, but there was no combined profession. From that day to this there has been a steady growth, until now this Institution represents a body of highly-trained engineers scattered all over the British Empire and over every part of the world, numbering more than 6 000, and with our students making a grand total of over 7 000. And when we know what the object of all these men is, to utilize the powers of Nature for the benefit of man, and when we know also that they are doing their duty, we have reason, I think, to be thankful for the growth which has taken place in this Institution. We have had the great pleasure of receiving you here 11 years ago; we have also the satisfaction of numbering an esteemed member of your Society among our honorary members, which is with us a position of very great honor—we rejoice to number among them Mr. Chanute. Every one of us on this platform feels this afternoon in welcoming you here, that in endeavouring to show you a little hospitality we are only returning in a very small degree the wonderful kindness which all of us have received whenever we have visited the United States. It is one of the things which gives us courage to cross the Atlantic. We think it is rather an undertaking to get across the Atlantic, but it is the anticipation of our reception there that encourages us to go. I began that experience a long while ago. It was in the year 1857 that I first went to the United States, and I spent nearly 12 months there. I was only a young man at that time, but I was received in the kindest way, and I learned a great deal that has been most useful to me ever since. No engineer goes from this side of the water without coming back, and pointing out that we have a great deal to learn from you. One reason for that is, you are not so much trammelled as we are with traditions. Traditions are very good things in their right place, but sometimes they are very obstructive. You folks in a newer country are able very often to push ahead in a manner which we cannot do. It does us good to be able to quote you and say, "See what our friends on the other side of the water are doing." Very often we are able by that means to introduce improvements in a way we otherwise should not be able to do.

Ladies and Gentlemen:—I have kept you quite long enough. My object is simply on behalf of this Institution to bid you a most hearty welcome. I want you to know that throughout this week all the facilities of this building, and, by the kindness of the Council of the Mechanical Engineers, the facilities of their building also, are extended to all American friends in London. I want to invite you to accompany us in the two visits that have been arranged for your enjoyment. When Her Majesty the Queen heard that our American friends were coming over, although she is in residence at Windsor, and it is very unusual for large parties to visit the Castle there when she is in residence, she said, "By all means let them come." There will be a special train for the purpose, and I hope as many of you as possible, especially the ladies, will join us in the expedition. On Thursday evening we hope to see you in the Guildhall. We usually have our conversazione or reception in this building, but there were two reasons why we altered the custom this year; one is this, that we want all our members to have an opportunity of meeting you, and when we have a reception here we have to take two evenings for the purpose because these premises are not commodious enough. Therefore, we are having it at the Guildhall, so that we can entertain nearly 4 000 people, and you will have a good opportunity of seeing what English engineers and their ladies are like. The other reason was this, that I think there is a great deal historically connected with the Guildhall which will be interesting to you. There are those remarkable figures, Gog and Magog; there is a splendid exhibition of pictures, and, with the addition of some music, I hope we shall enable you to pass a very pleasant evening.

Then comes Friday. The Countess of Warwick, when she heard we were thinking of taking you to that historic place, which we all like to visit, and I am sure you specially like to visit, the County of Shakespeare, said: "By all means; I will receive them at Warwick Castle myself." The Earl and Countess are kind enough to have accepted our invitation to meet you at luncheon in Warwick Park.

Before concluding, may I say that we have looked upon this week as a week of pleasure and not of business, and therefore we have not arranged visits to engineering works. But on behalf of my professional brethren, as well as on my own behalf, let me say if any of you gentlemen want to see works in the neighborhood of London, we will afford you every facility for the purpose.

I trust that our gathering here may be only one more means of binding us all closely together in the work that we have to do on both sides of the Atlantic, and I only hope that some day, not very far distant, we may have the pleasure of seeing you here again. I am rather doubtful whether it will be in this building, but it may be in another one, and you will then receive just as hearty a welcome from our successors as we are glad to offer you this afternoon.

JOHN F. WALLACE, President, Am. Soc. C. E.—*Sir* Douglas Fox, on behalf of the members of the American Society of Civil Engineers, I would like to express our feelings at the kind words we have received from the President of this Institution. The American Society of Civil Engineers occupies in America the same position that the Institution of Civil Engineers does in Great Britain, and we consider our principles broad enough to cover engineers of all specialties and all classes. There is a saying in America that engineers are not speakers, and as later in the day I have a matter upon my conscience which has troubled me very much, and as we in America always help each other when we are in a difficulty, I will call upon Colonel Haines, one of our most prominent engineers, to answer the words of welcome we have heard.

H. S. HAINES, M. Am. Soc. C. E.—*Sir* Douglas Fox, Ladies and Gentlemen:—I am, to repeat a trite expression, called on rather unexpectedly to support our honored President, but I know very well what a task he has before him. In listening, as I have and as you have, to the very cordial welcome just extended to us, I feel somewhat in the position of one delivering a prologue on the first performance of a new drama. And as I stand before the curtain that has not yet risen, I sympathize with those who are to take part in the performance, and upon whom rests the burden of its success or failure. For, Sir, the American Society of Civil Engineers has crossed the broad ocean to hold its meeting in this land before an audience thoroughly conversant with the subjects that it proposes to discuss; and as I heard your remarks on the subject I felt that its proceedings were about to be conducted under the roof of an Institution its senior by two generations, an Institution on whose roll of honor are inscribed names as familiar to us as household words, beginning, as you observed, with that of Thomas Telford, the Colossus of highway roads, and broadening as it descends, including the names of acknowledged leaders in every path of modern engineering. Under such conditions those of our members who are to take part in this meeting may well feel some trepidation at making their *début* in your midst, and I think that they will feel obliged to me if I state their position in such a way as to secure for them your favorable consideration in advance of the meeting. The topics which it is proposed to discuss are principally those in which your members have already acquired large experience, and we may hope to derive very great profit if we can have the benefit of that experience. One of those topics, however, is of such recent development that it may be sufficiently novel to you to be of some interest on that account at least. Be that as it may, on one thing we most confidently rely, that although we are in a land to which many of our members hitherto have been strangers, I feel sure that they will soon find that they are among friends, among those allied to them by all the ties which bound your forefathers to theirs until the time came that they crossed the Atlantic and planted the seeds on a far distant shore of that tree of liberty which now shelters a continent. To those ties, historical and political in their origin, we now hope that we may add others of a social as well as of a personal character, and that our sister societies may be bound together, as you very justly observed, Sir, in the bonds of friendship and of mutual help, in that common cause which we both undertake to promote, the utilization of the resources, the materials, and the forces of Nature, for the welfare of mankind. And it is in that spirit, Sir, that on behalf of the American Society of Civil Engineers, and of its President, I respond to the cordial welcome you have so graciously extended on behalf of the Institution of Civil Engineers.

JESSE M. SMITH, Vice-President, Am. Soc. Mech. Engrs.—*Sir* Douglas Fox, Members of the Council, and members of the Institution of Civil Engineers of Great Britain:—We regret exceedingly that our President, Mr. Morgan, cannot be present to express to you the sentiments which every member of the Society of Mechanical Engineers professes toward this revered Society of Civil Engineers of Great Britain. Those of us who accepted your very liberal hospitality in 1889 cannot but feel the great honor which you have conferred upon us again in inviting us here during this week. Those who were here in 1889, and I am speaking also for the Mechanical Engineers who were not here in 1889, miss the genial face and the cordial hand of him who was then your Secretary, Mr. Forrest. His mantle has fallen on Dr. Tudsbery, who has done everything possible for the comfort and entertainment of the American Engineers who are visiting your Institution, and we feel that the most royal reception which we received in 1889 is an earnest of what we are about to receive during the present week. I express to you, Sir, to the Council, and to the members of the Institution, our most hearty appreciation of your great kindness in inviting us here.

MINUTES OF MEETINGS.

OF THE SOCIETY.

September 5th, 1900.—The meeting was called to order at 8.35 P. M., Vice-President Rudolph Hering in the chair; Assistant Secretary McMinn acting as Secretary; and present, also, 65 members and 12 visitors.

The minutes of the meeting at the Annual Convention were approved as printed in *Proceedings* for August, 1900.

A paper by Elwood Mead, M. Am. Soc. C. E., entitled "Irrigation Studies," was presented by the Acting Secretary. The subject was discussed by Messrs. Mansfield Merriman and Rudolph Hering.

Ballots were canvassed and the following candidates declared elected:

AS MEMBERS.

Frank Alexander Barbour, Boston, Mass.
Robert Bruce Burns, Los Angeles, Cal.
David Janney Howell, Albany, N. Y.
Eugene Willett Van Court Lucas, Wilmington, N. C.
James Godfrey Warner, Perth, Western Australia.
Elton David Walker, Schenectady, N. Y.
Charles Valentine Weston, Chicago, Ill.

AS ASSOCIATE MEMBERS.

William Melvin Bailey, Malden, Mass.
Oliver W Childs, St. Louis, Mo.
Edward Francis Haas, San Francisco, Cal.
William Cushing Hammatt, Tepezalà, Mex.
Alexander Johnson, New York City.
Harrison Wainwright Latta, Philadelphia, Pa.
Elmer James McCaustland, Ithaca, N. Y.
Leon Solomon Moisseiff, New York City.
Edward Charles Murphy, Ithaca, N. Y.
Robert Blum Olney, Charleston, S. C.
Theodore Nelson Spencer, Philadelphia, Pa.

Announcement was made of the death of the following members: Dominik Lindenthal, elected Associate Member March 4th, 1896; died June 8th, 1900. William Giddings Curtis, elected Member May 3d, 1882; died June 15th, 1900. Edward Arnold Correa, elected Member March 7th, 1900; died June 24th, 1900. Hamilton Smith, elected Member February 5th, 1879; died July 4th, 1900. Collis P.

Huntington, elected Fellow March 10th, 1877; died August 13, 1900. Fairman Rogers, elected Member May 7th, 1873; died August 22d, 1900.

Adjourned.

September 19th, 1900.—The meeting was called to order at 8.35 p. m., N. P. Lewis, M. Am. Soc. C. E., in the chair; Charles Warren Hunt, Secretary, and present, also, 78 members and 35 guests.

A paper by L. G. Montony, Assoc. M. Am. Soc. C. E., entitled "The Ninety-sixth Street Power Station of the Metropolitan Street Railway Company of New York City," was presented by Mr. W. A. Low, and discussed by Messrs. A. Carr, W. Boecklin, Jr., J. D. Kent and W. A. Low.

A written discussion by F. L. Averill, Assoc. M. Am. Soc. C. E., was presented by the Secretary.

The Secretary announced the election of the following candidates by the Board of Direction, on September 11th, 1900:

As Juniors.

Shirley Baker, Sacramento, Cal.
Richard Turner Dana, Ridgewood, N. J.
Francis Burchard Harrington, Albany, N. Y.
Asa Warren Parker, Brooklyn, N. Y.

Adjourned.

OF THE BOARD OF DIRECTION.

(Abstract.)

September 11th, 1900.—The Board met at 8.17 p. m., Vice-President Noble in the chair; Charles Warren Hunt, Secretary; and present, also, Messrs. Hering, Knap, Manley, Ricketts, Schneider, Seaman and Whinery.

The subject of a proposed engineering exhibit and Society Convention in connection with the Pan-American Exposition, at Buffalo, in 1901, was considered.

Applications were considered and other routine business transacted.

Four candidates for Junior were elected.

Adjourned.

ANNOUNCEMENTS.

In accordance with the resolution of the Board of Direction the House of the Society is open every day, except Sunday, from 9 A. M. to 10 P. M.

MEETINGS.

Wednesday, October 3d, 1900.—A regular business meeting will be held. Ballots for membership and ballots on the proposed amendments to the Constitution will be canvassed, and a paper entitled "The Theory and Practice of Precise Spirit Leveling," by David A. Molitor, M. Am. Soc. C. E., will be presented for discussion. This paper is printed in the current number of *Proceedings*.

Wednesday, October 17th, 1900.—A regular meeting will be held, at which a paper entitled "The Preservation of Railway Ties in Europe," by Octave Chanute, Past-President, Am. Soc. C. E., will be presented for discussion. This paper is printed in the current number of *Proceedings*.

LIBRARY.

Up to December, 1898, there was published in *Proceedings* a monthly list of "Additions to the Library and Museum." This list was unclassified, and, while giving the titles of books or pamphlets received, could only be considered as a printed acknowledgment of donations. When the Publication Committee decided to undertake the "List of Current Engineering Literature," the publication of the former list was discontinued. The Publication Committee has now decided to publish a monthly list of acknowledgment of contributions, and the first installment, covering "Donations to the Library from January 1st, 1899, to September 1st, 1900," will be found on page 207.

The importance to the Society of the interest taken by members in its Library need not be dwelt upon, the fact that this list represents about 428 donors and 2 650 (gifts an average of about 137 per month) shows clearly that these accessions could not have been acquired by purchase; and there are doubtless many books, as well as official and private reports by our members which should be on file, but which have not been received.

Members are therefore urged, not only to forward such books and reports, but to call the attention of the Secretary to publications which, in their opinion, would be valuable, whether such publications may be secured for the asking, or whether they must be purchased.

A classified Catalogue of the Library will soon be ready for issue to members, and it is hoped that its publication will serve to awaken an interest in this branch of the Society's work which will result in the establishment and maintenance of a thoroughly up-to-date professional reference library.

MONTHLY LIST OF RECENT ENGINEERING ARTICLES OF INTEREST.

(August 8th to September 12th, 1900.)

NOTE.—*This list is published for the purpose of placing before the members of the Society the titles of current engineering articles, which can be referred to in any available engineering library, or can be procured by addressing the publication directly, the address and price being given wherever possible.*

LIST OF PUBLICATIONS.

In the subjoined list of articles references are given by the number prefixed to each journal in this list.

(1) *Journal*, Assoc. Eng. Soc., 257 South Fourth St., Philadelphia, Pa., 30c.
(2) *Proceedings*, Eng. Club of Phila., 1122 Girard St., Philadelphia, Pa.
(3) *Journal*, Franklin Inst., Philadelphia, Pa., 50c.
(4) *Journal*, Western Soc. of Eng., Monadnock Block, Chicago, Ill.
(5) *Transactions*, Can. Soc. C. E., Montreal, Que., Can.
(6) *School of Mines Quarterly*, Columbia Univ., New York City, 50c.
(7) *Technology Quarterly*, Mass. Inst. Tech., Boston, Mass., 75c.
(8) *Stevens Institute Indicator*, Stevens Institute, Hoboken, N. J., 50c.
(9) *Engineering Magazine*, New York City, 30c.
(10) *Cassier's Magazine*, New York City, 25c.
(11) *Engineering* (London), W. H. Wiley, New York City, 35c.
(12) *The Engineer* (London), International News Co., New York City, 35c.
(13) *Engineering News*, New York City, 15c
(14) *The Engineering Record*, New York City, 12c
(15) *Railroad Gazette*, New York City, 10c.
(16) *Engineering and Mining Journal*, New York City, 15c.
(17) *Street Railway Journal*, New York City, 35c.
(18) *Railway and Engineering Review*, Chicago, Ill.
(19) *Scientific American Supplement*, New York City, 10c.
(20) *Iron Age*, New York City, 10c.
(21) *Railway Engineer*, London, England.
(22) *Iron and Coal Trades Review*, London, England.
(23) *Bulletin*, American Iron and Steel Assoc., Philadelphia, Pa.
(24) *American Gaslight Journal*, New York City, 10c.
(25) *American Engineer*, New York City, 20c.
(26) *Electrical Review*, London, England.
(27) *Electrical World and Electrical Engineer*, New York City, 10c.
(29) *Journal*, Society of Arts, London, England.
(30) *Annales des Travaux Publics de Belgique*, Brussels, Belgium.
(31) *Annales de l' Assoc. des Ing. Sortis des Ecôle Spéciales de Gand*, Brussels, Belgium.
(32) *Memoirs et Compt Rendu des Travaux*, Soc. Ing. Civ. de France, Paris, France.
(33) *Le Génie Civil*, Paris, France.
(34) *Portefeuille Economique des Machines*, Paris, France.
(35) *Nouvelles Annales de la Construction*, Paris, France.
(36) *La Revue Technique*, Paris, France.
(37) *Revue de Mecanique*, Paris, France.
(38) *Revue Générale des Chemins de Fer et des Tramways*, Paris, France.
(39) *Railway Master Mechanic*, Chicago, Ill.
(40) *Railway Age*, Chicago, Ill., 10c.
(41) *Modern Machinery*, Chicago, Ill.,, 10c.
(42) *Transactions*, Am. Inst. Elec. Eng., New York City, 50c.
(43) *Annales des Ponts et Chaussées*, Paris, France.
(44) *Journal*, Military Service Institution, Governor's Island, New York Harbor, 75c.
(45) *Mines and Minerals*, Scranton, Pa. 20c.
(46) *Scientific American*, New York City, 10c.
(47) *Mechanical Engineer*, Manchester, England.
(48) *Zeitschrift des Vereines Deutscher Ingenieure*, Berlin, Germany.
(49) *Zeitschrift für Bauwesen*, Berlin, Germany.
(50) *Stahl und Eisen*, Duesseldorf, Germany.
(51) *Deutsche Bauzeitung*, Berlin, Germany.
(52) *Rigasche Industrie-Zeitung*, Riga, Russia.
(53) *Zeitschrift des oesterreichischen Ingenieur und Architekten Vereines*, Vienna, Austria.
(54) *Den Tekniske Forenings Tidsskrift*, Copenhagen, Denmark.
(55) *Ingenióren*, Copenhagen, Denmark.
(56) *Teknisk Tidskrift*. Stockholm, Sweden.
(57) *Teknisk Ugeblad*. Christiania, Norway.
(58) *Proceedings*, Eng. Soc. W. Pa. 410 Penn Ave., Pittsburg, Pa. 50c.
(59) *Transactions*, Mining Institute of Scotland, London and Newcastle-upon-Tyne.
(61) *Proceedings*, Western Railway Club. 225 Dearborn St., Chicago, Ill., 25c.
(62) *American Manufacturer and Iron World*, 59 Ninth St., Pittsburg, Pa.
(63) *Minutes of Proceedings*, Inst. C. E London, England.

LIST OF ARTICLES.

Bridge.

Hydraulic Method of Sinking Cast-Iron Piles, Moruya Bridge, New South Wales.* (21) August.

A Simple Method of Calculating the Curve of Equilibrium or Line of Thrust, in Arched Ribs. Charles Lean, M. Inst. C. E. (12) August 3.

The Bridge Work of the Pittsburg, Bessemer & Lake Erie and Union Railways.* (13) August 16.

The Franzens Bridge at Vienna.* (14) August 18.

The Riverside Drive Viaduct, New York.* (14) August 25.

Diagonal Bracing over the Turntable in Swing Bridges. Malverd A. Howe. (15) August 31.

The 721-Ft. Three-Hinged Steel Arch Railway Bridge across the River Viaur, France.* (13) Sept. 6.

The Maumee River Draw-Bridge.* (14) Sept. 8.

Pont à Arcades, Système Vierendeel.* A. Morizot. (36) Serial beginning March 10, ending August 10.

Les Embarcadères "Cantilever" de la Côte Cantabre.* A. Dory. (31) Pt. 2, 1900.

Electrical.

The Use of Aluminium Line Wire and Some Constants for Transmission Lines. F. A. C. Perrine and F. G. Baum. (42) June and July.

On the Photometry of Arc Lamps.* F. W. Carter. (26) Serial beginning July 13, ending August 3.

Gloucester Electricity Works.* (26) August 3.

Alternating Current Induction Motors.* A. C. Eborall. (47) Serial beginning August 4, ending August 25.

Electrolytic Interrupters.* Benj. F. Bailey. (27) August 11.

The Electric Generating System of Prague.* Fred. Bathurst. (26) August 17.

Prof. Pupin's Proposed System for Long-Distance Telephoning. H. T. Wade. (13) August 23.

Electricity—A Few Examples of Its Application to Mining.* (22) August 24.

Operating Economies in Central Station Practice. W. L. Abbott. (26) August 24.

On Some Methods of Determining Experimentally the Moments of Inertia of the Rotors of Dynamos and Alternators. Alfred Hay, M. I. E. E. (26) Serial beginning August 24, ending August 31.

Dielectric Strength. James Rowland Bibbons. (27) August 25.

The Electrical Equipment at the Indian Head Naval Proving Grounds.* (27) August 25.

The British Insulated Wire Company's Works at Prescot.* (26) August 31.

The Slaby-Arco System of Wireless Telegraphy.* (26) August 31.

Applications of Electricity in the Collieries of Great Britain.* Sidney F. Walter. (9) Sept.

Electrical Ignition of Gas Engines. H. J. Poddlesak. (41) Sept.

Electricity in Large Cities; Its Transmission and Distribution. W. S. Barstow. (10) Sept.

High Voltage Incandescent Lamps. Prof. Geo. D. Shepardson. (27) Sept. 1.

Nernst Lamp at the Exposition.* (46) Sept. 1.

Some Features of Electric Lighting and Tramway Practice.* (47) Sept. 1.

Dynamotors *versus* Motor Generators. Alton D. Adams. (27) Sept. 8.

Grue Électrique à Charpente Mobile: Construite par MM. Mohr et Federhaff, à Mannheim.* (36) August 25.

Marine.

Machinery for the United States Navy Armored Cruisers. Rear-Admiral G. W. Melville. (11) August 3.

Notes on Wreck Raising. David W. Noakes. (11) August 17.

On the Mechanical Theory of Steamship Propulsion. Robert Mansel. (12) August 24.

First-Class Battleship *Kentucky*.* (46) Sept. 1.

The First-Class Battleship *Alabama*.* (46) Sept. 8.

Mechanical.

Automobile Vehicles.* Prof. Louis Derr. (1) July.

Automobiles. Dr. T. J. Martin. (1) July.

The Balancing of Engines. MacFarlane Gray. (47) Serial beginning August 4, ending August 11.

The Use of Gas Engines in Connection with Electric Power Plants. Philip Dawson. (11) August 10.

Recent Experiments in Mechanical Flight. Hiram Maxim. (29) August 17.

The Campbell Oil Engine.* (47) August 18.

An Improved Slide Valve for Steam Pumps.* (47) August 18.

Reheaters in Multiple-Cylinder Engines. Prof. R. H. Thurston. (47) August 18.

Boiler Explosions Discussed. T. R. Parker. (62) August 23.

The Nordberg Pumping Engine at Wildwood, Pa.* (13) August 23.

Some Designs of Metallic Packing.* (47) August 25.

Compressed Air Motors in Chicago. (40) August 31.

Controlling Speed of Gas Engines.* (41) Sept.

Gas Engine Fuels, Types, and Uses.* Professor C. V. Kerr. (10) Sept.

Mechanical—(Continued).

Heavy Motor Vehicles for Road Service.* Fred. W. Maynard. (9) Sept.
A Simple and Practical Means of Recording Steam-Engine Performance.* W. Ripper. (9) Sept.
Observations on Retorting and Condensing Temperatures. Forbes Waddell. (24) Sept. 10.
Distribution à Tiroirs Cylindriques et Échappement Independant.* N. de Tedesco. (36) August 10.
Évaluation de la Force Transmise par Courroie sur les Poulies de Grand Diamètre et à Grande Vitesse. (33) August 25.

Military.

The "Drift" and "Throw" of a Projectile. J. Bridges-Lee. (11) Serial beginning July 13, ending August 3.
The Gruson Rotating Turret: Features of Advantage as an Effective Coast Defense Arrangement.* T. Guilford Smith. (62) August 2.
Creusot Guns on Disappearing Carriages.* (19) August 25.
Ranging with Field Guns. Major H. B. Stanford. (44) Sept.
Le Nouvel Appareil Directeur pour Torpilles Automobiles.* H. Noalhat. (36) August 25.

Mining.

Gold Dredging in New Zealand.* P. G. Morgan. (16) Serial beginning August 4, ending August 18.
Mining Operations near Halifax, N. S.* (16) August 11.
A Successful Method of Mining Iron Ore Used at the Pewabic Mine, Michigan. Dr. M. P. Hulst. (22) August 31.
Accidents in Coal Mines. Thomas K. Adams. (45) Sept.
Rib Drawing with Machines: A Proposed New Method of Mining Coal by the Use of Longwall Undercutting Machines for Taking out the Rib.* W. S. Gresley. (45) Sept.
Rope Transmission in Mine Haulage.* (45) Sept.
Signal Device for Mines.* C. S. Herzig. (45) Sept.
The Compressed-Air Haulage-Plant at No. 6 Colliery, Glen Lyon, Pennsylvania. J. H. Bowden. (16) Sept. 8.

Municipal.

The Action of Water on Asphalt Pavements.* Daniel B. Luten. (13) August 16.
The Construction of Asphalt Pavements. Geo. W. Tillson, M. Am. Soc. C. E. (14) Sept. 1.
Notes on Landscape Architecture. (14) Sept. 8.
Les Pavés Artificiels et la Fabrication des Briques au Moyen du Schiste Houiller.* Cyrille Jansens. (30) August.

Railroad.

Some Peculiarities of Steel Rails.* (22) August 3.
Railway Blacksmithing. (47) August 4.
Can Small Electric Railways be Operated at a Profit? James Blake Cahoon. (17) Serial beginning August 4, ending Sept. 1.
New Type of Piston Valve.* (18) August 11.
The Paris Metropolitan Underground.* (27) August 11.
The Utilization of Water Power for the Electric Railway System of Minneapolis and St. Paul.* Edward P. Burch. (17) August 11.
The Bois de Boulogne Combined Trolley and Surface Contact Tramway.* (26) August 17.
Notes on Electric Traction. A. H. Binyon. (47) August 18.
Machine Snow Plows on the Colorado Midland Ry. (13) August 23.
New York Central's Track Improvement.* (40) August 24.
Rail Making Problems. (22) August 24.
Hydraulic Embankment Filling, Canadian Pacific Railway.* (18) August 25.
Interlocking System, New South Station at Boston.* (18) August 25.
The Paris Metropolitan Underground Railroad.* (46) August 25.
Standards of Track Construction on American Railways. (13) August 30.
Load Factors on Traction Stations. William H. Booth. (26) August 31.
Oak Point Yard—New York, New Haven and Hartford.* (15) August 31.
The Proposed 5½ by 10 M. C. B. Journal Box.* F. M. Whyte. (25) Sept.
Wide Firebox 10-Wheel Passenger Locomotives.* (25) Sept.
Wightman's Cylinder and Frame Fastening, used by Pittsburgh Locomotive Works on Large Pittsburgh, Bessemer & Lake Erie Locomotives.* (25) Sept.
The Metropolitan Railway of Paris.* (17) Sept. 1.
Operating Methods of the Columbus Railway Company.* (17) Sept. 1.
Creeping of Rails on the St. Louis Bridge. (13) Sept. 6.
Back Lights. (15) Sept. 7.
Revision of the Weehawken Yards, New York Central.* (15) Sept. 7.
Le Nouveau Matérial à Bogies pour Trains Rapides de la Compagnie du Chemin de Fer du Nord.* M. Defauconpret. (38) July.
La Traction à Air Comprimé: Nouvelles Installations en Cours d'Exécution à Paris. A. Monmerqué. (38) July.
Le Funiculaire de Montmartre, à Paris.* J. Laverchère. (33) August 11.

Sanitary.

Septic Sewage Disposal at Liberty, N. Y.* (14) August 18.
Deep Sewer Trenching.* (14) Sept. 1.

Structural.

International Specifications and Methods of Testing Iron and Steel from an American Engineer's Standpoint. William R. Webster, M. Am. Soc. C. E. (11) Serial beginning August 3, ending August 10.
Testing Cement by the Modulus of Rupture for Transverse Strain. John Paterson, Assoc. M. Inst. C. E. (12) August 10.
A Multiple Hot Water Supply. (14) August 11.
The Sanitary Equipment and Power Plant of a Modern Lodging House.* (19) August 11.
Evolution of Steel Casting. (62) August 16.
Blast Furnace Smelting by Water Gas. C. C. Longridge, M. Inst. M. E. (12) August 17.
Foundry Flasks. E. H. Pierce. (22) August 17.
The Atlantic Mutual Insurance Company's Building.* (14) August 18.
A New Method of Blast Furnace Construction.* F. Burgers. (16) August 18.
The Relative Corrosion of Wrought Iron, Soft Steel and Nickel Steel. Henry M. Howe. (16) August 18.
Ventilation and Heating in the Metropolitan Museum of Art, New York. (14) August 18.
Hydraulic Engineering in the Metropolitan Power House.* (20) August 23.
Experiments on the Relation of Stress and Strain, and Repeated Stresses. (47) August 25.
The Generation of Intense Heat through the Combustion of Aluminum.* S. B. Archdeacon. (16) August 25.
The Manufacture and Care of Chilled Rolls. (22) August 31.
New Steel and Iron Foundry of the Sargent Company.* (15) August 31.
On Wöhler's Laws. J. Gilchrist. (12) August 31.
Standardized Cast Iron. (11) August 31.
Fire Hazards. H. De B. Parsons. (3) Sept.
On the Annealing of White Cast Iron. Charles James. (3) Sept.
The Construction of Moisture-Proof Underground Chambers. L. R. Grabill. (13) Sept. 6.
Building for a Large Ice-Making Plant.* (14) Sept. 8.
The Hans A. Frasch Electrolytic Process for Extracting Metals as Applied to Copper-Nickel Matte. (16) Sept. 8.
Malleable Cast Iron. (16) Sept. 8.
Les Palais de l'Esplanade des Invalides.* Louis David. (33) August 4.
Applications du Pétrole à la Métallurgie et à l'Industrie du Verre.* G. de Krivochapkine. (33) August 25.

Water Supply.

A New Rack and Other Improvements to the Feeder for the Middlesex Company, Lowell, Mass.* Arthur T. Safford. (1) July.
Official Duty Tests of Pumping Engines Nos. 9 and 10, High-Service Station No. 3, St. Louis Water-Works, February 15-16 and 26–27, 1900. Nils Johnson. (1) July.
Godalming Water-Works.* (11) Serial beginning August 3, ending August 17.
Operation of the Water Settling and Filtration Plant at Albany, N. Y. (13) August 9.
Tests of Centrifugal Pumps under High Heads. Lewis A. Hicks. (13) August 9.
Water Measurement and Manipulation in Colorado.* H. A. Crafts. (46) August 11.
New Water-Works Extension in Glasgow.* J. A. Stewart. (19) August 18.
Report of the Merchants' Association on the Water Supply of Greater New York. (13) August 23.
The White Plains Water-Works.* (14) August 25.
English Practice in Cleaning Water Mains with Scrapers and Brushes.* (13) August 30.
Experimental Test of a Concrete and Expanded Metal Conduit for the Jersey City Water Supply.* R. Godfrey. (13) August 30.
The Marlborough Brook Filter Beds; Metropolitan Water Supply for Boston and Vicinity. (13) August 30.
Niagara Falls Works. Orrin E. Dunlap. (26) August 31.
Commercial Requirements of Water-Power Governing. Elmer F. Cassel. (9) Sept.
Irrigation in Idaho. Waldon Fawcett. (46) Sept. 8.

Waterways.

Reservoirs and the Control of the Lower Mississippi.* James A. Seddon, M. W. S. E. (4) August.
The Improvement of the South Pass of the Mississippi River.* William Starling, M. Am. Soc. C. E. (13) August 23.
American Ore Dock Machinery.* Arthur C. Johnston. (10) Sept.
The Improvement of Non-Tidal Rivers by Regulation. (14) Sept. 1.
Travaux du Port Extérieur de Bilbao.* L. Coiseau. (32) July.
L'Achèvement du Canal de la Marne à la Saône.* G. Leugny. (36) August 10.
Notice Relative aux Travaux Exécutés, à l'Aide de la Cloche-Plongeur à Sas d'Air, aux Pivots des Portes d'Ebbe de l'Écluse Maritime du Kattendijk, à Anvers.* Pierrot. (31) Pt. 2, 1900.

NEW BOOKS OF THE MONTH.

Unless otherwise specified, books in this list have been donated to the Library by the Publisher.

MUNICIPAL IMPROVEMENTS.

A Manual of the Methods, Utility and Cost of Public Improvements, for the Municipal Officer. By W. F. Goodhue. Third Edition, revised and enlarged. Cloth, 7 x 5 ins., 8 + 207 pp., illus. New York, John Wiley & Sons, 1900. $1.75.

In this work the author has aimed to aid those city officials who, while familiar with the general plan and scope of public improvements, are uninformed as to the details. The contents are: A Sewerage System; Street Car Lines; Street Sprinkling; The Street Surface—Pavements and Implements; Gas Consumption; Street Lighting; Street Grades; A Water-Works System; A Municipal Franchise; Bridges; Methods of Assessment Against Real Estate; Building Laws and Ordinances; Cleanliness and Public Health; Public Cemeteries; Public Parks; A Public Library; Elevated Traffic *vs.* Subways; Civil Service Appointments; Municipal Ownership.

THE WATER SUPPLY OF THE CITY OF NEW YORK.

An Inquiry into the Conditions Relating to the Water Supply of the City of New York. By The Merchants' Association, of New York. Cloth, 9 x 6 ins., 627 pp., maps. New York, 1900. $3.00. (Donated by the Merchants' Association.)

NEW YORK'S WATER SUPPLY.

Report upon New York's Water Supply; with Particular Reference to the Need of Procuring Additional Sources, and their Probable Cost, with Works Constructed under Municipal Ownership, Made to Bird S. Coler, Comptroller, by John R. Freeman, C. E., March 23d, 1900 (with notes added while revising proof-sheets). Cloth, 10 x 7 ins., 587 pp., pl., maps. New York, Martin B. Brown Co., 1900. (Donated by the Author.)

DAS EISBRECHWESEN IM DEUTSCHEN REICH.

Auf Veranlassung des Königlich Preussischen Herrn Ministers der Offentlichen Arbeiten, dargestellt von M. Görz und M. Buchheister. Cloth, 11 x 8 ins., 243 pp., 46 pl., illus. Berlin, A. Asher & Co., 1900. (Donated by Paul Glasenapp.)

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS AND DISCUSSIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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THE THEORY AND PRACTICE OF PRECISE SPIRIT LEVELING.

By DAVID A. MOLITOR, M. Am. Soc. C. E.

TO BE PRESENTED OCTOBER 3D, 1900.

INTRODUCTORY.

In presenting this paper to the Society, the writer is actuated by the conviction that the subject of precise spirit leveling has not received the exhaustive treatment which it manifestly deserves, and that a clear and comprehensive exposition of the latest developments and methods would be, at this time, of great value to the profession. A further object is to elevate the standards of spirit leveling to the point of truly scientific work.

Leveling, as commonly conducted, belongs to the most primitive surveying operations. However, when there is presented the problem of spanning the continent by lines of levels which shall be as accurate as the highest skill and most perfect instruments will permit, then it may be truly said that the primitive art has advanced to the status of a science.

Leveling is simple only when it is permissible to neglect all small errors; it becomes more complicated and requires more painstaking in proportion to the accuracy required.

NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers with discussion in full will be published in *Transactions*.

The ultimate aim in precise leveling is to perform level work which is absolutely free from error, so far as this is attainable with the highest human skill, ingenuity and perseverance, combined with the use of the best instruments.

To manipulate a high-grade instrument with celerity and accuracy is artistic; to observe correctly, determinine all possible sources of error and eliminate these errors by proper methods of observing and by constant vigilance, is truly scientific. When all this is to be accomplished in the fields or on the public highways, exposed to the elements and many interfering annoyances, it seems almost miraculous to attain the results which some observers have obtained. Despite all these hindrances the subject demands a delicacy of instruments and an accuracy of results quite equal, or even superior, to the highest grade of geodetic work.

There are very few men who have made a success of precise leveling, and, of these, less than a half-dozen have given to the profession the results of their experience and study. Hence, the subject has advanced very little during the past fifteen years, and anyone detailed to such work is confined to very limited resources aside from his own. Also, the inducements offered are generally such that first-class men will not follow up precise leveling as a specialty, although the subject demands a specialist in the highest sense.

For this reason the writer hopes to add some new information to this important branch of geodetic work, by giving a complete treatise on precise leveling according to his own experience and research.

The historical side of the subject is so well treated in the report of the Geodetic Conference,* February 28th, 1894, that no attempt is here made in that direction.

In view of the many diverse opinions, theories and methods hitherto advocated, the present paper will be confined to the most practical and approved methods, and doubtful features will be discussed only when it is deemed necessary. The system of leveling here outlined is essentially that used by the United States Lake Survey and the Mississippi River Commission, with many changes which suggested themselves to the writer while engaged by the United States Board of Engineers on Deep Waterways, in running a duplicate line of precise levels along the St. Lawrence River from Tibbett's Point, N. Y., on

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* "Report of U. S. Coast and Geodetic Survey," 1893, Pt. 2, p. 304.

Lake Ontario, to the Canadian Boundary Line at St. Regis, N. Y.; also by the United States Lake Survey in running a duplicate line around Lake St. Clair, from Grossepoint to New Baltimore, Mich.

It is not deemed necessary to state the fundamental principles and definitions of terms involved in common leveling. The reader is supposed to be familiar with the definitions given in textbooks on surveying, and these will be used so far as they are found applicable.

In common levels it is customary to neglect all refinements which are supposed to prevent only small errors, but not to affect the material accuracy of results. It is not generally considered necessary even to equalize back and fore sights, or to shade the instrument from the sun, or to plumb the rod with a spirit level or plumb line. However, this is a gross neglect, for most of these things can be done without additional expense, and, as will be shown later, are much in the interest of good work. The question always confronts us: What is the limiting magnitude of a so-called small error? Some of these neglected errors are likely to be surprisingly large.

The method of differential spirit leveling, as executed with the wye level, is, in principle, circumscribing a polygon around the earth's surface by a succession of tangential lines. If the earth were a perfect sphere of uniform radial attraction at all points of its surface, then no error would be introduced into a line of spirit levels so long as back and fore sights are made equal, assuming that no deleterious atmospheric influences exist.

However, the earth is not a sphere, but an ellipsoid of revolution, thus making the theory of precise spirit leveling quite complicated. This it is proposed to discuss in the following under the head of errors.

In all following discussions and data, the metric system of weights and measures will be used exclusively, that system being almost indispensible to the class of work here considered.

PRECISE LEVELING INSTRUMENTS.

1. General Remarks.

There are a number of high-grade levels manufactured in different parts of the world. All makers are striving to attain the greatest perfection, yet the majority fall far short of the mark. The difficulty seems to be that the makers are not precise levelers and hence do not fully know and appreciate the fine points required in such instruments. Also, the various methods of observing demand a variety in the construction of certain details which will not be harmonized until all observers have accepted a generally approved system of leveling.

Another difficulty in the way of progress is that the makers are peculiarly obstinate, and show a marked indisposition to alter their designs of instruments to better suit the requirements of the engineer. A battle of words is generally necessary to convince the maker of a desirable improvement, and, when convinced, he will adopt the improvement only when specially ordered. This applies more strictly to American makers, probably because American engineers, generally, are more easily satisfied and seem to entertain a high degree of confidence in the ability of the maker to produce the best possible instrument.

There is, for example, no need for the ordinary wye-level, this instrument being more than replaced by a transit with a few slight modifications which could be made without material increase in cost. Yet the makers (with few exceptions) will not adopt the progressive move, probably because it would prevent the sale of common levels.

The ordinary wye-level, no matter how well made, is very imperfect in principle and does not permit of quick and reliable work, although intended for that very purpose. The reasons for this will be brought out more clearly in the following.

No instrument has ever been made of which it could be said that it was free from error or could be made so by the most careful adjustment of its parts. Hence, the observer can place absolutely no reliance on any instrument for permitting perfect adjustment or for holding such adjustment longer than a few minutes at a time. His confidence and assurance of perfect elimination of error must rest on his own ability to accomplish this end, and the instrument which best permits this difficult achievement necessarily deserves the credit of being the most perfect.

It is by no means intended to convey the impression that the most perfect level is necessarily the most complicated. On the contrary, simplicity is a prime necessity to the usefulness of a level, and its peculiar purpose demands strength, durability, compactness and stability of all its parts. Being subject to somewhat severe treatment, for an instrument of such fineness and delicacy, it follows that to fill the requirements imposed, and especially to permit of easy, certain and rapid manipulations in the field, a perfect precise level becomes one of the most painstaking productions of the maker. To add to the difficulty of perfecting the design of levels, the maker has not the practical experience necessary to know the exact purpose to which he must adapt his instrument, but must base his ideas of purpose on a very meager, often conflicting, collection of requirements.

2. Description of Various Precise Levels.

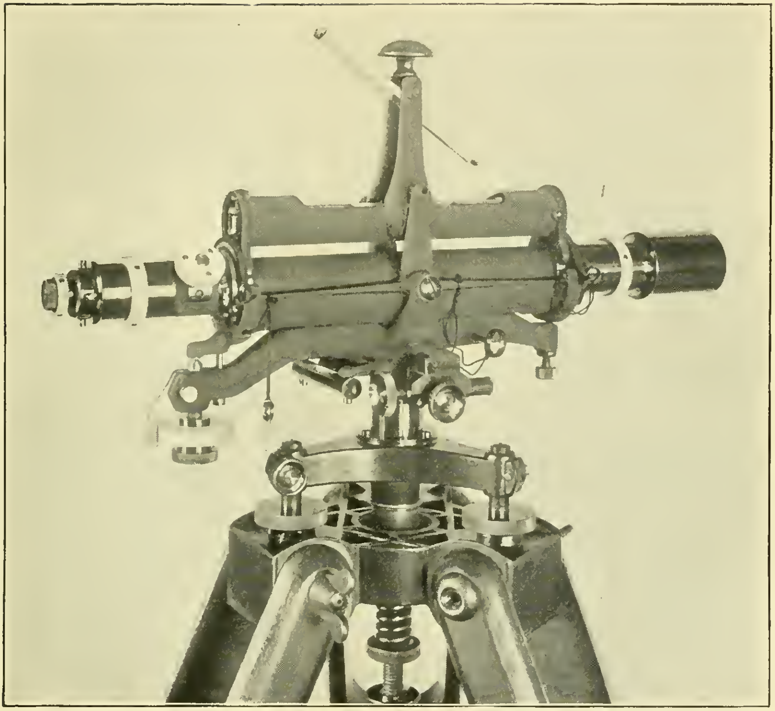
a. Buff and Berger Precise Level No. 2768.—This level, shown on Plate XXXIV, was made in 1897, essentially according to the design of Professor T. E. Mendenhall, President of the Worcester Polytechnic Institute. It combines simplicity of construction with practical and substantial design and excellent workmanship, and is believed by the writer to be the most perfect precise level yet produced.

As previously stated, that instrument is the most perfect which best permits the elimination of all errors directly in the observations themselves, even though the adjustments of the instrument are somewhat imperfect and variable, a defect which can never be entirely avoided. This instrument may be said to permit this in a higher degree than any other known to the writer.

Perhaps the most important feature of a precise level is a good telescope, of high power, comparatively large aperture, perfect definition within limits of the telemeter threads, careful mounting of the lenses, especially of the objective, and true movement of the eyepiece in the telescope tube without a trace of lateral looseness.

In this level the telescope is supplied with two carefully ground steel collars upon which it is supported in any position by four agate points, in the wye cradle. The striding level tube rests on these steel collars, forming four points of contact. The cross-threads and eyepiece are readily adjustable and are mounted in the end of a tube of almost the same length as the telescope, thus absolutely preventing all irregularity of motion. The material is generally phosphor- or aluminum-bronze, which is probably as good as any, though steel would be preferable were it not so subject to corrosion.

The striding level tube is of quite equal importance to the telescope, and a certain necessary relationship should exist between the



Buff and Berger Precise Level, No. 2768.

two in order that they may be equally efficient in obtaining accurate readings. That is, for the maximum allowable length of sight, the error of pointing, due to the delicacy of the level tube, must be far within the attainable accuracy of a single rod reading with a telescope of given magnifying power.

The striding level, therefore, contains a most accurate and sensitive tube, which is mounted carefully in a bronze case, permitting vertical and lateral adjustments. This level tube has an air chamber at one end, thus making the length of the bubble adjustable for all ordinary temperatures. An adjustable revolving mirror reflects the bubble image to the eye of the observer in either position of the tube. A level tube should never be mounted rigidly in cement or plaster of Paris, as was done originally in the above instrument. A thin strip of cork or blotting paper, wrapped around one end of the glass tube and held by screw pressure within the case, is all that is required. The other end may be carried on two points and held in position by spring pressure.

The level tube may be reversed simply by lifting it out of the guides and replacing it in a reversed position. The telescope may be revolved on its collars through 180°, and its horizontal thread is made horizontal by adjustable stops on each side of the cradle at the eye end of the telescope. The striding level must always be removed when the instrument is being carried and while revolving the telescope.

The foregoing features constitute the vital points of a precise level, and the remainder of the instrument is of minor importance, though many of the details are extremely valuable in facilitating quick and accurate handling of the instrument. Perhaps the best and most practicable mounting of the telescope and level tube yet devised is represented in this instrument.

The cradle, taking the place of the wyes in a level of ordinary construction, is centrally mounted on a horizontal axis intersecting the vertical axis of the instrument. Hence, any tilting of the cradle that may be desirable to bring the bubble to the center of the level tube, does not in the least affect the height of instrument, so that the instrument need only be made approximately level by the small tubular spirit levels attached to the rigid frame, and the fine leveling is then done by means of the large milled-head micrometer at the eye end.

The rigid wye of the common level is thus replaced by a swinging cradle which is adjusted to the level tube at every observation, thus transferring the movement of the wyes from the coarse leveling screws to a single delicate micrometer screw.

The cradle may be clamped rigidly by the screw at the right, but this is not considered useful or desirable.

The celluloid trimmings are intended to prevent temperature changes caused by handling the instrument.

The three leveling screws are admirably well adapted to this instrument, and permit of a generally low spindle and a very broad base on the tripod head, which makes the instrument very steady even for high wind, and the numerous other disturbing elements with which the observer is constantly molested. The tripod legs are also very rigid and serve their purpose well.

b. The Swiss Precise Level.—This level, shown in Fig. 1, Plate XXXV, was manufactured by Messrs. Kern and Company, of Aarau, Switzerland. It embodies essentially all the features described in the Buff and Berger level, though, in general, it is not so well constructed, and the level tube cannot be reversed on the telescope except by unclamping the lock device at the eye end of the instrument, which is somewhat annoying. The circular watchglass level for approximate setting of the instrument is a little better than the two small levels on the Buff and Berger level, which latter are partially covered by the lower frame. The level tube and telescope are much better than the remainder of the instrument.

The only objections to this instrument are: The short eyepiece tube, which frequently shifts laterally, thus introducing thread errors; the cradle joint not being in the vertical axis introduces errors from releveling; and the screws and other small parts generally are too light, and hence do not wear well.

The Kern level was first used in this country by the United States Lake Survey in 1876, and was retained on all precise leveling under the United States Engineer Corps prior to 1899. Fig. 1, Plate XXXV, shows the most improved form, though the older levels were almost the same except that the mirror was fastened at one end of the level tube case, and did not permit of reading the level tube direct and reversed.

The Kern level is undoubtedly the oldest high-grade instrument

PLATE XXXV.
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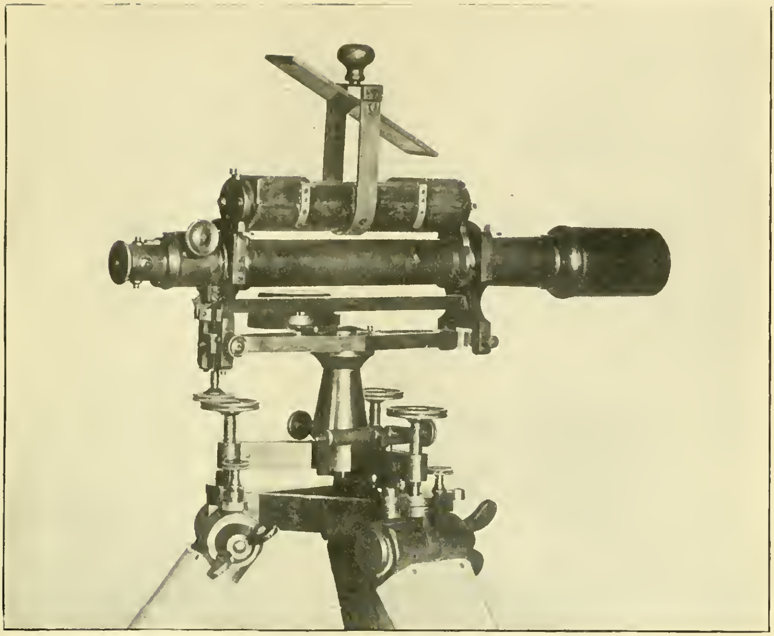

Fig. 1.—Kern Precise Level.

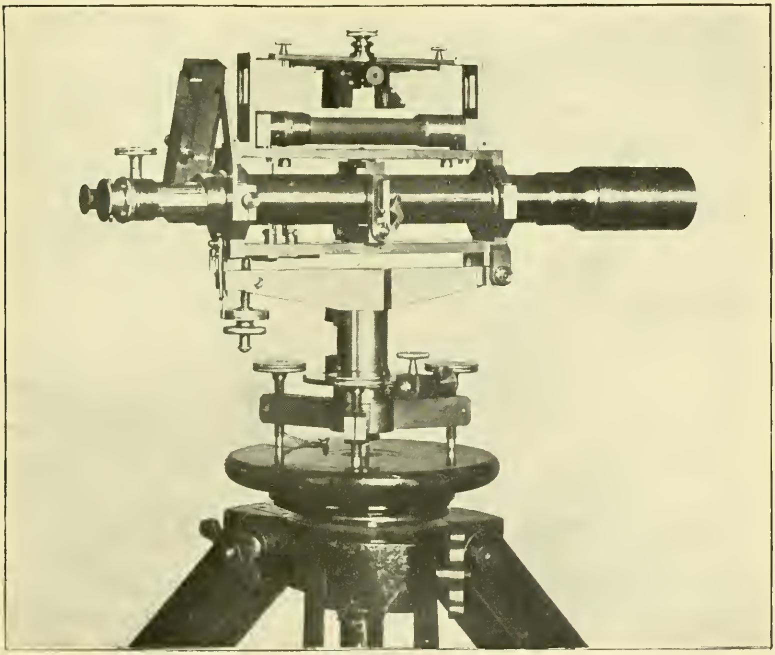

Fig. 2.—French Government Level.

made, and has maintained its excellence to the present day, being exceeded by none in quality of material and workmanship, though being somewhat superseded in details by the Buff and Berger level designed by Professor Mendenhall.

c. *The French Government Level.*—This level, shown in Fig. 2, Plate XXXV, was made by A. Barthelemy, of Paris, and used on the *Nivellement Général* of France. It is an instrument of somewhat different type from those just described. The illustration is taken from a photograph of the level at the College of Civil Engineering, Cornell University.

With the exception of the level tube, this instrument is almost exactly like the Kern level, and all criticisms offered regarding the latter level apply equally to the French level. Hence, it will be sufficient to describe only the exceptional construction of the level tube, which, in a general way, may be said to represent a most complicated solution of one of the least troublesome features of a precise level.

The idea in this level tube is to produce an image of the bubble which may be seen from, or near, the eyepiece of the telescope without parallactic error. To accomplish this, the image of each end of the bubble is carried by adjustable prisms, attached to the horizontal frame of the level tube, to a trough near the eye end of the telescope, in which four other prisms carry these images to an eyepiece, seen to one side of the telescope eyepiece. This is certainly a complicated solution of a small difficulty so readily solvable by an ordinary mirror, as is done in the two levels previously described. That the parallax of the bubble image in an inclined mirror can be easily prevented, and that even when allowed to exist it eliminates itself from the work when back and fore sights are made equal, will be shown later.

However, granting, for the present, that such a complicated device were necessary, it is readily seen that the manner in which it is here applied is not at all satisfactory, because the two eyepieces are about 25 mm. or 1 in. apart, and hence the bubble cannot be observed at the instant of taking the rod reading, which fact is far more objectionable than a slight parallax. Also, in reversing the level tube the prisms over the level must be reversed and refocused, which consumes time and is apt to disturb the instrument.

As will be seen from Table No. 1, this instrument is not nearly as delicate, in point of magnifying power and level tube curvature, as are those previously described.

d. The United States Coast and Geodetic Survey Level.—This instrument, shown in Fig. 1, Plate XXXVI, was designed and made in the shops of the Survey, and represents the type of level used by this bureau of the Government prior to 1899. Some changes in this instrument, as also in the field methods used by the Survey, have been made recently, but these have not yet been made public, and hence only a passing reference will suffice to point out a few of the most striking features which are different from other high-grade levels.

The general design does not differ materially from the Swiss instrument. There is no means, either by mirror or otherwise, of observing the bubble simultaneously with the rod, which is a very serious omission. Also, there is no coarse level for approximate setting of the instrument, and hence this must be done with the striding level in two positions, which is a slow process. A novelty (supposedly) is introduced by a system of bearings or wyes, inside the principal wyes, for the purpose of raising the telescope off its supports while it is being revolved on its horizontal axis, to prevent the wear usually attending this manipulation. However, as has been intimated, and as will be brought out more clearly in another place, this is not necessary, because the wear of the collars does not influence the relation existing between the level tube and the telescope, except when the tube contact and the wye points of support are on the same circles of the telescope collars, which is seldom the case and should be avoided in all instrument designs.

e. The Massachusetts State Survey Level.—This instrument, shown in Fig. 2, Plate XXXVI, was constructed by Messrs. Buff and Berger, of Boston, Mass., and used also by the United States Geological Survey. It is not really a precise level, but merely a good common level.

This instrument, in principle very much like that shown on Plate XXXV, embodies most of the features of a precise level, but, without a striding level tube, it cannot be considered as such. The focusing is accomplished by motion of the objective, which is somewhat inconvenient to the observer. This instrument could readily be altered to become a very good level for precise or common work merely by removing the fixed level and replacing it with one that can be used as a combined striding and fixed level, as is done on the Buff and Berger

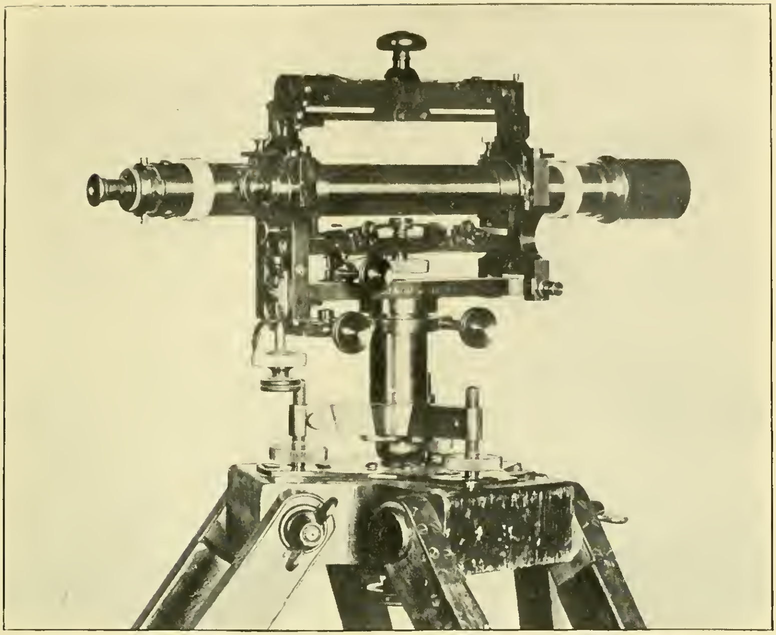

FIG. 1.—U. S. COAST AND GEODETIC SURVEY LEVEL.

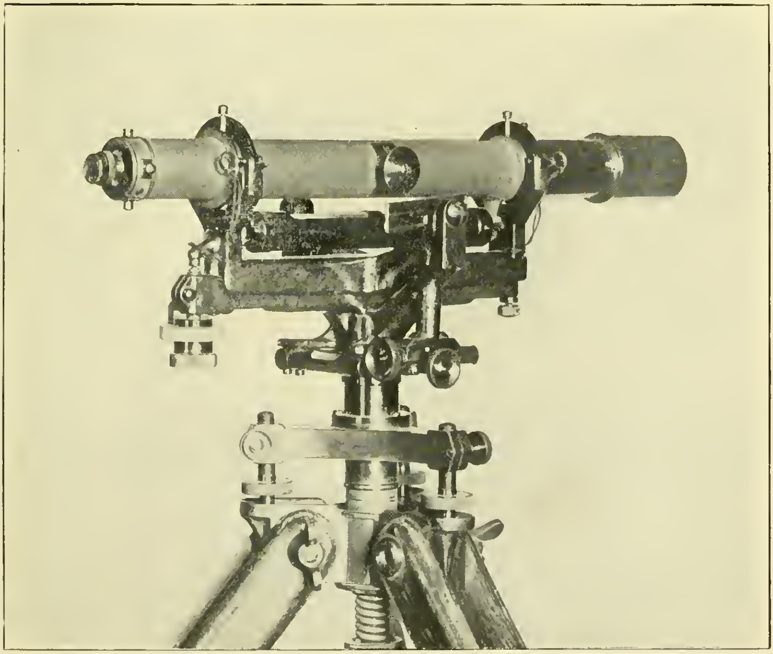

FIG. 2.—MASSACHUSETTS STATE SURVEY LEVEL.

TABLE No. 1.—Constants of Various Precise Leveling Instruments.

Instrument.	Material.	Telescope.					Level Tube.			Weight.			Quick Leveling.	Wye Cradle Pivoted.	Leveling Screws.
		Focal Length.	Diameter of Obj.	Focusing.	Magnifying Power.	Thread Distance.	Type of Level.	Level Reading Device.	Curvature per 2-mm. Division. Seconds.	Instrument.	Stand.	Total.			
		mm	mm		dia.	ratio.				Kgr.	Kgr.	Kgr.			
a. Buff & Berger Level No. 2768. Pattern of Professor Mendenhall	Steel and Bronze.	410	38	eyepiece	50	1:200	Reversible striding.	Revers. mirror over level.	5.0 changed to 2.23.	5.3	7.6	12.9	Two tubular plate levels.	on center	3
b. Swiss Level, Kern & Co., No. 2............	Steel and Brass.	370	37	"	50	1:231	"	"	1.7 to 3.4	5.0	5.8	10.8	Circular watchglass level.	on end	
c. French Government Level. By A. Barthelemy, Paris............	"	360	36	"	25	......	"	Prismatic eyepiece.	8.26	5.4	6.3	11.7	"	"	3
d. U. S. Coast and Geodetic Survey. Level used prior to 1899.....	"	348	29	"	28	1:180	"	None.	2.1	4.5	6.2	10.7	None.	"	3
e. Massachusetts State Survey. By Buff & Berger, Boston........	Steel and Bronze.	380	38	objective	35	1:100	Fixed.	Metallic side mirror.	6.4 to 8.0	5.6	4.7	10.3	Two tubular plate levels.	on center	3

plane table alidade. However, the mirror should not be omitted, and the form used in Plate XXXV would be preferable to that here used.

The properties of the five instruments just described are given in Table No. 1.

3. Salient Features of a Precise Level.

For a general criterion or standard of excellence of a precise level the following will serve as a guide:

The telescope should be about 420 mm. long, have an aperture of about 38 mm., and a magnifying power of about 50 diameters. It should be readily reversible and invertible in its cradle supports. The focusing should always be accomplished by movement of the eyepiece, and the latter should be absolutely free from all lost motion and wobbling. The position of the telescope in the cradle should be regulated by adjustable stops (but no clamps), so that the threads may be made exactly horizontal when the telescope is normal or inverted. The thread distance of extreme wires should be 1:200, or 5 mm. per meter of distance. There should be one vertical and three horizontal threads, and the two half intervals should be as nearly equal as possible.

The level tube should have a curvature of about 2 seconds per division of 2 mm., have an air chamber, and be adjustable vertically and laterally. The bubble must be surmounted by an adjustable mirror, so that parallax is eliminated in both positions of the level and mirror.

The level tube should rest on the telescope collars on four points which are not on the circles passing through the points of contact between these collars and the cradle supports. The tube should be guided laterally and horizontally, so that the contact points between it and the collars shall remain the same, but it shall be otherwise free so that reversals may be readily made without any unclamping, etc.

The cradle support, taking the place of the wyes of an ordinary level, should swing vertically about a center in the vertical axis of the instrument, so that releveling will not change the elevation of the telescope. The cradle should be movable by means of a large micrometer screw working against a counter spring. The instrument should be supplied with a small watchglass level for approximate and quick leveling (not for taking readings), thus leaving the micrometer only for fine setting for each individual rod reading.

4. Precise Level Rods.

Like the levels, the style of rod has passed through many stages of evolution, and, even at this time, widely different opinions exist in regard to the best material, cross-section, graduation, etc., to be used.

a. The Material.—This has generally been wood, and clear, white pine seems to have received the preference. Various methods of treating the wood have been used and advised, and the whole matter appears to be resting more or less on individual opinions.

The usual treatment consists of several coats of linseed oil covered by several coats of white zinc paint. This treatment has given good satisfaction, generally, and the old Lake Survey rods, made by Kern & Company, thus prepared, have given excellent results and withstood hard usage for the past 24 years. The United States Coast and Geodetic Survey, in 1895, prepared two pine rods by immersion in hot paraffin until they had increased from 70 to 95% in weight. Similar rods, recently made for the United States Geological Survey by Messrs. W. and L. E. Gurley, of Troy, N. Y., were treated with paraffin to a penetration of about 3 mm.

However, the experience with paraffin rods would go to show that this treatment causes the wood to become soft, and prevents the perfect adhesion of paint. A partial saturation with linseed oil would not injure the wood, as the oil soon hardens and thus lessens the hygroscopic property of the wood. The oiled wood is also well prepared to hold the white paint, which latter is claimed, by Colonel Goutier, to assist materially in lessening the effect due to moisture. According to the determinations of the United States Coast and Geodetic Survey, the paraffin treatment would appear to increase the coefficient of expansion of pine wood about 50%, which would be another undesirable feature of this process.

b. Cross-Sections.—Various cross-sections have been used for leveling rods, but the general consensus of opinion tends toward a T-section, unless the graduation, or other appliances, like targets, influence the choice.

c. Graduation.—The style of graduation depends on whether a target rod is used or a self-reading rod. For the former, any common, easily readable scale, with vernier, will answer. Perhaps the most elaborate target rods ever constructed are those designed by the United States Coast and Geodetic Survey.*

The rod used on the general levels of France, and designed by Col. Goutier, is more on the order of a self-reading rod with the smallest graduation of 2 mm. However, the graduations are not well adapted to close estimation, being more on the principle of line graduation. This rod has a very ingenious device for making temperature corrections, which consists of a metallic thermometer of iron and brass bars attached to the bottom of the rod and allowed to expand upward. Such a rod forms part of the collection of the Department of Civil Engineering of Cornell University.

The Kern level rods, previously referred to, are graduated to centimeters by a double system of black and white figures, upon which it is intended to estimate at least to millimeters. After much practice and study of the subject of estimating, a careful observer can estimate to from 0.2 to 0.5 mm. for sights up to 80 m. with a magnifying power of 50 diameters, though this is a difficult task, requiring exceptional eyesight and long practice. Few observers ever reach such precision. However, these rods† were used on all the work done under the Corps of Engineers, United States Army.

Without stopping to quote numerous opinions of others, the following brief argument is presented to show the superior practicability of self-reading rods over target rods. In general, with a good instrument and well adapted rod graduation, the position of a thread on the rod can be as sharply read as it is possible to set a target, because the space covered on either rod or target by the thread itself vitiates a target setting more than a direct estimation. The target, wherever set, can be read with a vernier or other fine device, but such accuracy will be farcical, not real. Hence, if there is to be an error in pointing it might as well be made in the rod reading as in the target setting.

Further, the accuracy of direct reading, so far, has been found to be well within the limits of attainable accuracy owing to many conditions of atmosphere and instruments used.

With a suitable graduation, the probable error of repeated pointings made on a target and duplicated on a self-reading rod, show no superiority of the former even when only one thread is read on the latter. With precise methods, however, it is necessary, for other reasons, to read three threads, and then the accuracy attainable with the self-reading rod is far higher.

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* Described and illustrated on page 381 of the Survey report for 1895.

† Further description and illustration of this rod may be found in *Transactions*, Am. Soc. C. E., Vol. xxxix, p. 421.

The most important feature of the self-reading rod is, however, the rapidity and absolute control of the instrument which the observer enjoys when he is independent of all actions of the rodman, save that the latter shall hold his rod plumb and quiet. With this system alone is it possible for the observer to take the responsibility of his work and follow the now generally accepted method of observing with the bubble in the center.

It may be added that ordinary work can be done with greater accuracy with a self-reading rod than with a target rod, and usually the readings can be taken in less time than is required to set the target only approximately correct. Hence, the self-reading rod deserves decided preference for all classes of work, from the coarsest to the finest. There is only one exception known to the writer, and that is on construction work, where, for instance, a number of piles should be sawed off at the same level, or such similar cases, when a target rod would come handy, although many errors are attributed in such cases to slipping or erroneous setting by the rodman.

d. New Self-Reading Rod.—A new self-reading rod, designed by the writer in 1899, is illustrated in Figs. 1, 2 and 3. This design is the result of much experience and careful study, and involves the simplest figures which are discernible at the greatest distance.

The design is based strictly on the self-reading principle, and thus enables the observer to read, practically without counting anything, from the coarsest down to the finest graduation. The fraction of the smallest graduation (2 mm.) is then estimated with a precision proportional to the distance and the quality of the instrument used. This rod is, therefore, well adapted to the coarsest as well as the finest kind of work.

By exercising great care, good readings may be obtained from 1-cm. graduations, but the faculty for close estimating soon tires. Hence, to increase the general accuracy of the work, lessen the strain on the observer, and facilitate progress, a self-reading rod with 2-mm. unit graduations is considered necessary.

The following specifications for a pair of such rods will suffice to give a good description of the rod and its appurtenances:

"Two level rods complete, each with handles, spirit level, plumb-bob and thermometer, shall be furnished, packed in a light pine box provided with hinged cover and locks. The size of rods and style of graduation is shown on the sketch hereto attached (see Figs. 1, 2 and 3).

"A flexible steel scale, 4 m. long, divided into centimeters, except the first 10 decimeters, which shall be divided into millimeters, shall be furnished on a reel 8 ins. in diameter and mounted in a neat carrying case, provided with a handle and lock cover. The scale shall be numbered by decimeters from 0 to 40. The reel shall be so mounted in the case as to permit of drawing out and winding up the scale without removing the reel from the case. A thermometer, as specified below, shall be furnished with this scale, and be attached to the case.

"The rods shall be made of the best seasoned white pine wood, well impregnated with linseed oil and then dried, preferably by application of slight heat. The beaded edges of the rod shall be made of clear hard maple or oak, similarly treated. After the rods have been thorougly sandpapered, especially the faces to be graduated, they shall be painted a sufficient number of coats of best white zinc paint and thoroughly dried, after which they may be graduated, as shown on the drawing.

"The 2-mm. graduations shall be accurately marked on the painted rods by a graduating machine, and the figures afterward constructed on this graduation shall be painted black.

"Each rod shall be provided with a pair of detachable handles and a watchglass level capable of easy adjustment. These shall be securely fastened to the rod, where indicated on the sketch, by a very substantial fastening, using small brass bolts instead of wood screws. All metal parts and trimmings shall be of brass.

"The pin at the foot of each rod, together with its yoke, shall be cast from best phosphor-bronze, free from lead and very hard. This pin shall be truly faced, making its bottom surface perpendicular to the axis of the rod. Otherwise the pin shall be dressed on an emery wheel and be rigidly connected to the foot of the rod by brass bolts. The distance between the bottom of this pin and the zero of graduation must be made exactly equal in the two rods.

"A mercurial thermometer, registering half degrees Centigrade between + 50° and — 15° (No. 245, Catalogue, H. J. Green) shall be inlaid in the wood of each rod and be covered by a small glass plate. This thermometer shall be placed near and over the spirit level. A similar thermometer shall be provided with the flexible steel scale and be fastened inside the case.

"A small plumb-bob, not larger than 1 in. in diameter, shall be

Dimensions are in centimeters

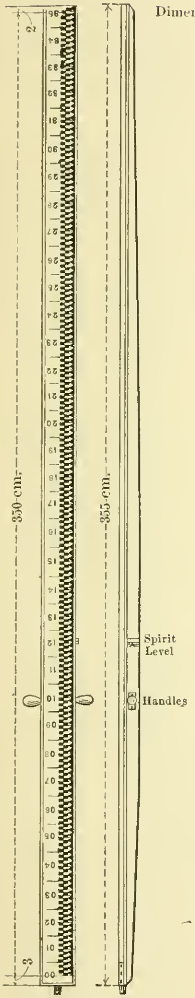


FIG. 1.

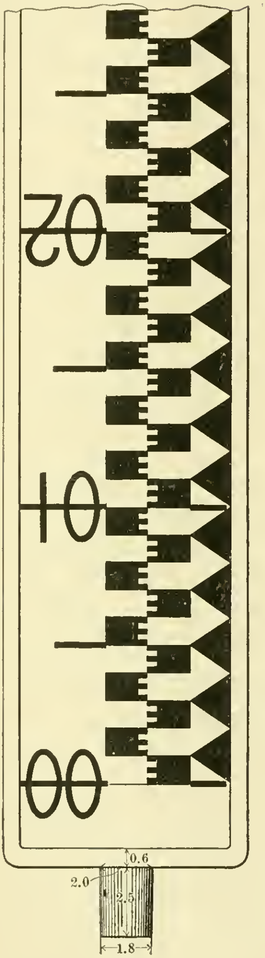


FIG. 2.

SELF-READING
PRECISE LEVEL ROD,
DESIGNED BY
DAVID MOLITOR, M. AM. SOC. C.E.
JAN. 16TH, 1899.

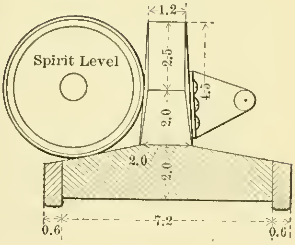


FIG. 3.

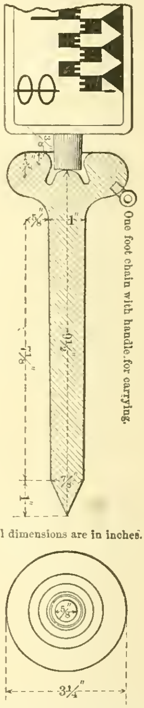
furnished with each rod, and the rods shall be provided with small brass points and hooks between which the plumb-bob may be swung when the spirit level is being adjusted. Such a pin point is shown in plan, in Fig. 3.

"The two rods, with handles, spirit levels, plumb-bobs, etc., shall be packed neatly in a light but durable pine box, in which they may be transported and preserved. Care should be taken to maintain the smallest possible dimensions for this box, as it is not desirable to have this part of the outfit unnecessarily heavy."

Readings taken on this graduation, with Buff and Berger Precise Level No. 2768, showed that the greatest error in a single reading would vary from 0.2 to 0.4 mm. for distances of from 10 to 85 m., respectively. The steel scale is intended for tri-daily rod comparisons to furnish the error of rod length and temperature correction to be applied to the work. The same scale is also intended to replace the rod when reading on bench-marks on which the rod cannot be held.

e. Precise Level Rod Supports.—The supports which have given the best satisfaction consist of steel pins, as shown in Fig. 4. These pins are driven into the ground with a wooden mallet, and, with ordinary care, furnish a support which is as safe as a temporary bench-mark. There has never been the slightest indication of heaving or settling when these pins were used.

The general idea of using a steel pin was originated in France and Germany many years ago, but the form here illustrated, with a slightly different head, was first used by Mr. O. W. Ferguson, United States Assistant Engineer.



All dimensions are in inches.

FORGED STEEL TURNING POINT FOR PRECISE LEVELING.

FIG. 4.

It is needless to take up the discussion of pins *versus* foot-plates, as the latter are considered entirely out of date.

BENCH-MARKS.

Two classes of bench-marks are generally used in precise leveling, the permanent and the temporary. The former are designed for permanent and lasting record while the latter are necessary only in carrying the work between the permanent benches, and thus serve only a temporary purpose.

According to American practice, the temporary benches are made by driving a 60-penny wire spike in the root of a large tree, the root being first dressed off with a hatchet. Frequently, large boulders are found which are preferable to trees. With a cold chisel a smooth, rounded surface is worked on a suitable part of the boulder, and this point is enclosed by a square, likewise cut into the stone. These benches are always numbered so as to preserve their identity for some time.

The permanent bench-marks are placed either on substantial permanent public or private buildings, on bed-rock, or subterraneous monuments of stone or concrete. The mark itself generally consists of a ¼-in. copper or brass bolt cemented into the structure or monument, and is placed horizontally or vertically as each case requires.

The horizontal bolts are made square ended, cemented flush with the masonry and marked with a fine center punch mark for the elevation point. The vertical bolts are round headed and made to project about ⅛ in. above the stone. The name and number of each bench is chiseled into the stone near the mark.

The American public has not yet reached the generally high regard and appreciation for scientific work found to exist in Germany and France, and, for this reason, it is not always prudent to place marks, intended for permanence and security, in plain sight. Hence, the subterraneous monuments, while they are more difficult to describe and find, are by far the most permanent.

In the more advanced European countries the permanent benches are always placed in plain sight and provided with a cast-iron or bronze name plate, giving the name of the department by which established, the name of the bench and its elevation in meters above mean sea level or normal datum plane. For Germany, this datum is the permanent bench-mark of the Berlin Astronomical Observatory,* at elevation 37 m.

The United States Geological Survey has adopted a uniform system of permanent bench-marks† which is similar to some forms used in France and Germany. While it is sought to overcome the many destructive tendencies of our population by specifying the fine for disturbing these marks, it is needless to add that the offence must be proven before a fine or other punishment can be imposed, and to this extent little is accomplished by the law. The safe plan is to conceal bench-marks in such a manner as not to invite the maliciously inclined to do mischief. Yet, this condition will probably be improved in the course of time, and it may become safe to adopt such a form of bench for general use.

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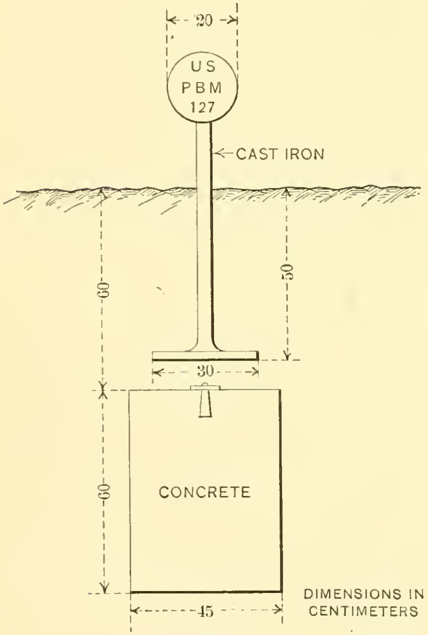
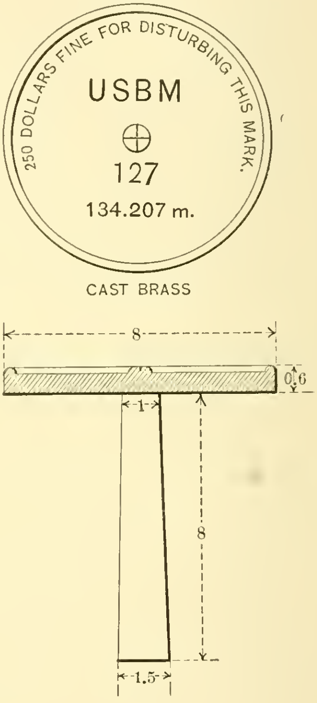
* "Handbuch der Vermessungskunde," by Dr. W. Jordan, Vol. 2, p. 456.

† *Transactions*, Am. Soc. C. E., Vol. xxxix, p. 342.



1.20

Fig. 5.



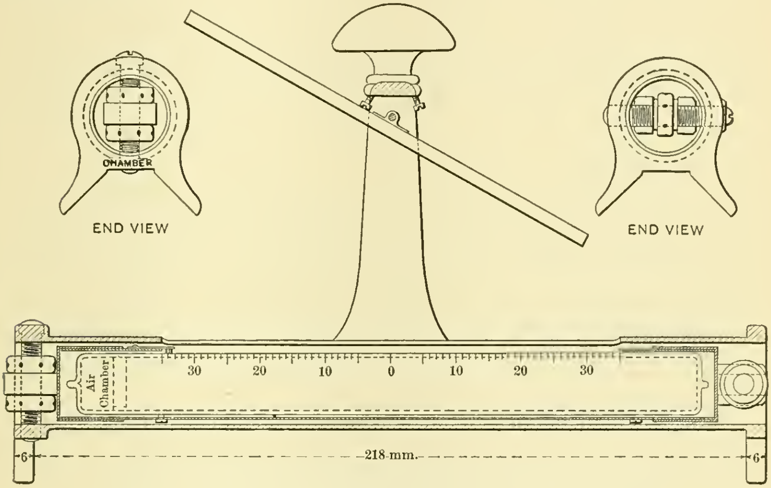
1:2

Fig. 6.

There are many instances where bed-rock or permanent buildings are not available, and then the subterraneous monument forms the best and safest bench-mark. A cast-iron surface marker should be used, and be placed in some definite position with reference to the hidden monument, as, for instance, 5 ft. south. Such a bench is illustrated in Fig. 5. A name-plate suitable for this or for buildings is shown in Fig. 6, and is quite similar to the Geological Survey mark. When the name-plate is placed in a vertical wall, the point held on should be marked by a fine cross, cut as shown, though this is not necessary when used in a concrete bench.

The number can be stamped on the name-plate at the time of placing the bench-mark, and the elevation would best be supplied on a separate plate, which could be fastened with two small screws.

The concrete base may be made by carefully digging a hole of the required diameter and depth, filling it to the desired level with cement concrete, and finally placing the name-plate before the concrete has set.



LEVEL TUBE OF BUFF AND BERGER PRECISE LEVEL, No. 2768.
SECTIONAL VIEW.

FIG. 7.

THE SPIRIT LEVEL.

There are some features about very sensitive spirit levels, as used on precise leveling instruments, which deserve special consideration.

a. Level Tube.—The level tube is made cylindrical, of extremely hard glass, and is then ground, generally on one side only, to the arc of a circle, whose radius varies from about 50 m. to several hundred meters, depending on the desired sensitiveness. This tube is filled with absolute sulphuric ether, with the exception of a small air bubble, the length of which may be read on a scale graduated on the glass tube. The ends of the tube are closed by fusing (never by cement), and near one end a ground glass disc with a small notch is inserted in the tube to form an air chamber by which the length of the bubble may be regulated (see Fig. 7). The length of the level tube should be about 200 mm., and its external diameter about 19 mm.

The numbering of the graduations of the level is generally from the center toward the ends, though some makers have adopted a continuous numbering from one end to the other. The writer has used both styles and has reached the conclusion that for spirit leveling the graduation from the center is far more preferable, and does away with all reductions to the center necessary with the new style. The chances of misreading or erroneous centering are also much greater for the continuous graduation. The only argument in favor of the latter is that the reading identifies the end of the level, but in spirit leveling this is not important except when reading bubble displacements, which is done only in connection with determinations of instrument constants.

The level tube is encased in a metal tube and is held in this tube at one end by slight screw pressure against blotting paper or cork wrapping on the glass tube, and the other end is left free to slide on two points against which the glass tube is pressed by a spring. In no instance should the glass tube be cemented into the metal tube at either end. Such rigid fastening is likely to break the tube, and prevents its keeping in adjustment.

This metal case is carried in the casing proper, or frame, in which the level tube may be adjusted laterally at one end and horizontally at the other end.

b. Sensitiveness of the Level Tube.—The sensitiveness of the level tube depends on the curvature of the tube and the length of the bubble. There may also be irregularities due to improper grinding. Grit, not properly removed from the tube after grinding, or corrosion of the glass by the ether, may cause unevenness in the movements of the bubble.

The angular value corresponding to a movement of the bubble over a distance of one graduation (generally 2 mm.) may be found by the use of a level trier, or by rod readings taken with different positions of the bubble. The level trier is very convenient, and especially well adapted to test the uniformity in grinding over the entire length of the tube. However, for field use the rod readings are preferable and quite as accurate, and the curvature thus determined represents more nearly the actual condition, compared with indoor measurements on a level trier.

The bubble should be retained at an almost constant length of about half the length of the ground portion of the level tube. This makes the air chamber of prime necessity.

A short bubble has a very sluggish movement even in the most sensitive tubes. This is caused by the high friction along the glass compared to the slight lifting power of the small bubble. There is no danger from excessively long bubbles except the practical limit of the graduation.

According to Reinhertz, a level tube of 10.8 seconds per division of 2 mm. gave the mean error of position of bubble for different lengths of bubble as follows:

Length of bubble........	4.9	13.3	22.2	28.9 divisions;
Mean error of position....	1.0	0.5	0.3	0.3 seconds of arc.

The sensitiveness best suited to high-grade work is between 2 and 5 seconds per 2-mm. division, ranging with the rigidity of the instrument and tripod, the ground traveled over and the delicacy of manipulation of which the observer is capable. The writer has found no difficulty in using a 2-second level tube on Buff and Berger Level No. 2768, even in windy weather, with no other shelter than a large wagon umbrella.

c. Temperature Effects on Level Tubes.—The sensitiveness of a level changes with the temperature. Hence, all level readings, used in such a manner as to involve the value of the level graduation, will have a temperature correction which must be determined previously, and the value of a graduation should be expressed as a function of temperature. To illustrate this effect, the following figures are quoted from experiments by Reinhertz:

(t) temperature, degrees Centigrade,	—2.2°	+9.0°	+ 19.7°	+27.7°
(v) seconds per one division of level,	8.46″	7.65″	6.12″	5.67″

The equation representing the value of one division of this level for any temperature within the observed range is $v = 8.2 - \frac{t}{10}$ seconds.

Rapidly changing temperature causes much annoyance, and introduces an uncertainty which prohibits the use of sensitive levels, even when shaded by an umbrella. The latter should always be used on precise level work.

The length of the bubble changes materially with the temperature, and the rate of change depends on the sensitiveness of the level. The data in Table No. 2, taken from the above-named experiments, will illustrate this. The length of the bubble is thus inversely proportional to the temperature.

TABLE No. 2.

Value of level per division. Seconds.	LENGTH OF BUBBLE IN DIVISIONS.			Change per 1° *C.*
	0° *C.*	15° *C.*	30° *C.*	
5	32	25	18	0.45 div.
10	30	24	18	0.35
15	26	22	18	0.28
20	24	20	17	0.24
30	23	20	18	0.18

THE TELESCOPE.

A brief description of the telescope and its vital parts is considered necessary to a clear understanding of many of the points treated in the following.

a. The Laws of the Lens.—The only forms of lenses used in telescopes for surveying purposes are the double convex and its special case of plano-convex.

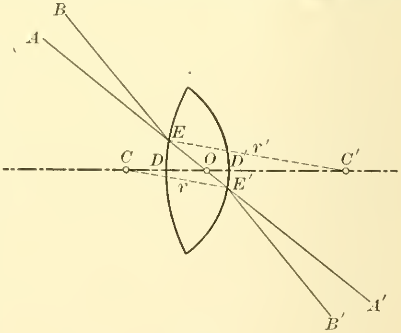


FIG. 8.

The axis of a lens is the line joining the centers of curvature of its two surfaces, and in a plano-convex lens the axis is perpendicular to the plane surface and passes through the center of curvature of the curved surface.

The optic center of a lens is the point, any ray passing through which suffers no refraction. The only point satisfying this condition is on the optic axis, and divides the thickness of the lens proportionally to the radii of curvature. Hence the simple construction in Fig. 8, for finding the optic center.

The radii r and r' are drawn parallel, and the optic center O is at the intersection of EE' with CC'. The ray AA' passes through the optic center and is not bent by refraction, while the ray BB', not through O, is refracted, making $BE \parallel B'E'$. It is readily seen that in a plano-convex lens the optic center is on the curved surface at the intersection with the optic axis.

The focal length of a lens is found from the following formulas :

For double convex lenses

$$f = \frac{1}{(n-1)\left(\frac{1}{r} + \frac{1}{r'}\right)}$$

For plano-convex lenses

$$f = \frac{r}{n-1}$$

in which n is the refractive index of the glass, and r and r' are the radii of curvature of the lens surfaces.

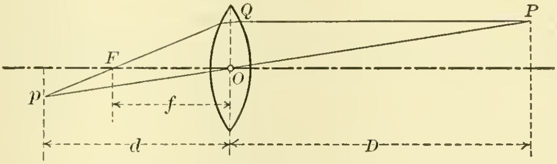


FIG. 9.

The rays from any point of an object distant D, from the optic center of a lens, converge to a focus on the opposite side of the lens, forming an image at a distance d, from the optic center, according to the general law expressed by

$$\frac{1}{D} + \frac{1}{d} = \frac{1}{f}$$

Such a pair of points are called conjugate points, and all rays parallel to the optic axis of a lens, or passing through the optic center of a lens, are called principal rays.

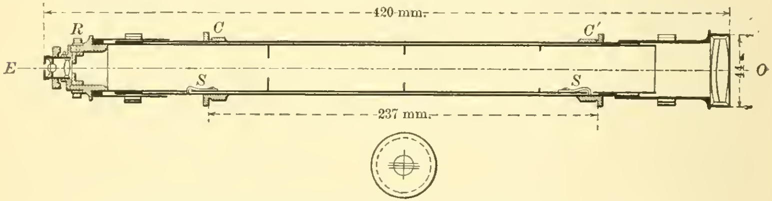
In the above equation when $D = \infty$, $f = d$, giving a ready means of determining the focal length of a lens by direct measurement. When D varies between infinity and $2f$, $d > f$, and the image is always inverted and demagnified, which is the condition of an objective lens. For values of D between zero and f, d becomes negative and the image is magnified but not inverted, which is the case of a magnifying lens or eyepiece.

When the position of a point or object is known with reference to a certain lens, the conjugate point or image may be found (Fig. 9) by drawing the two principal rays through this object; thus $P\ Q$ parallel to the axis of the lens and through the focus F, and $P\ O$ through the optic center of the lens. The intersection, p, of $Q\ F$ produced and $P\ O$, is the image of P. This construction can be readily made when f is known, and applies as well to the case when d is negative.

To correct spherical aberration good lenses are generally made with slightly unequal curvature on the two surfaces, and the flatter surface should face the object.

The foregoing general principles will suffice to make the construction of a telescope understandable.

b. The Telescope.—The telescope consists of a lens forming the objective at O, Fig. 10, mounted in a metal tube into which slides a second metal tube carrying the eyepiece lenses at E and the reticule at R, which latter must be at the focus of the objective.



TELESCOPE OF BUFF AND BERGER PRECISE LEVEL, No. 2768.

FIG. 10.

The eyepiece lenses are arranged so that they may be focused on the threads of the reticule, and both are made to move together, by rack and pinion motion, to bring the reticule to the focus of the objective. Thus the reticule is made to coincide with the inverted and demagnified image of the objective at R, and both are seen through the magnifying lens (or lens combination) of the eyepiece. Hence, the image in such a telescope is always inverted unless a special set of erecting lenses is added to the eyepiece, which is not advisable owing to loss of distinctness and loss of light caused thereby.

The tube of the eyepiece must slide in the telescope tube without lateral play and in a straight line. To insure this, the eyepiece slide should be very nearly the full length of the telescope and be pressed against one side of the telescope tube by four springs S, placed in pairs 120° apart.

The entire telescope is supported on agate points of a cradle against steel collars C and C' of exactly equal diameters, and rigidly connected with the tube of the objective forming the body of the telescope. The entire telescope can thus be revolved about an axis passing through the centers of the two collars. This axis is the axis of the telescope or axis of collimation, and, in a perfect instrument, the optic centers of all the lenses and the center of the reticule should be on this axis.

The line joining the optic centers of the eyepiece and objective is termed the optic axis. The line of sight is the line joining the optic center of the objective with the center of the reticule, and is independent of the position of the eyepiece, and not coincident with the axis of the telescope, unless made so by the maker and by adjustment. The extent to which this may be accomplished will be shown later.

c. The Objective.—The objective consists of a double convex lens of crown glass cemented to a concavo-convex or plano-concave lens of flint glass, supplying the very essential property of achromatism. This combination may be regarded as a double convex lens, for all practical purposes, and should have a long focal length so as to give the largest possible inverted image. The laws of the simple lens apply also to this combination.

The diameter of the objective governs the illuminating power of the telescope, and for this reason the objective lens should be as large as possible, consistent with other details of construction. Neglecting loss of light from obstructions in the lens itself and color effect, the relative illuminating power of a telescope is approximately represented by $i = \frac{\delta^2}{5\,m^2}$, where δ = diameter of objective in millimeters, and m = magnifying power of the telescope in diameters. The natural illumination is taken as unity.

d. The Eyepiece.—The eyepiece may consist of a single lens or a combination of lenses. The single lens is subject to spherical and chromatic aberration, and is, therefore, inferior to the combinations which are designed to avoid either or both of these defects. The Ramsden eyepiece, consisting of two plano-convex lenses with the convex surfaces toward each other, corrects spherical aberration, but is not achromatic, while the Kellner and Steinheil combinations are both achromatic and free from aberration.

The eyepiece is simply a magnifier of the image formed by the objective, and, as such, does not influence the errors of the telescope. Very bad mounting would interfere with the sharpness of definition in parts of the field of view and should be avoided, to the extent of obtaining sharp definition.

The focal length of a compound eyepiece is expressed in terms of the focal lengths of its respective lenses and the distance, a, between their optic centers, by the following formula:

$$f = \frac{f' f''}{f' + f'' - a}$$

e. The Reticule.—This was invented by William Gascoigne in 1640, and consists of a ring interposed in the eyepiece slide of the telescope perpendicular to the telescope axis. It is made adjustable horizontally and vertically by four capstan screws, Fig. 10 *a.* Four spider threads are mounted on this ring, one vertical and three horizontal. The two extreme horizontal threads are used for distance determinations, and incidentally give a means of increasing the number of readings to eliminate errors of estimation. They serve an almost indispensable purpose in avoiding misreadings. The intersection of the mean horizontal and the vertical threads marks the aiming point on the line of sight for the eye-end of the telescope.

The interval between the extreme horizontal threads is so chosen that the intercept formed by them on a vertical scale or rod is some even fraction of the distance of such rod from the instrument. Owing to the high magnifying power of the eyepiece generally used on precise levels, this interval should be such that the ratio between rod intercept and distance should not exceed the ratio 1:200, and may be still smaller, up to 1:500, though 1:200 does not approach the limits of sharp definition of the eyepiece, and yet is very convenient for converting rod intervals into actual distance. Smaller ratios, of course, give less accurate distance determinations.

The actual horizontal distance, l, is determined from the rod intercept, i, or wire-interval, by the well-known stadia formula,

$$l = k\,i + c + f \text{ for horizontal sights,}$$

in which k is the stadia constant, preferably 200 for levels, f is the focal length of the objective, and c is the distance from the center of the instrument to the optic center of the objective.

Hence, for any number, n, of successive settings of an instrument the continuous distance for a stretch of levels would be

$$L = \Sigma_o^n \, l = k \, I + 2n \, (c + f)$$

where $\Sigma_o^n \, l$ is the sum of all back and fore sights of the stretch, and $I = \Sigma_o^n \, i$ is the sum of the thread distances, or rod intercepts, for all back and fore sights. This formula seems complicated, but, in practice, its solution is made very simple by tabulating the function $k \, I$ for values of I from 1 to 100. However, when k is exactly 200, a condition which the maker can supply, then no tabulation is necessary.

f. The Steel Collars.—These form a very important feature of the telescope, and, as might be inferred from what has already been said, the direction of pointing of the telescope depends on the condition that these collars are exactly equal and that they remain equal. This condition is never realized in practice, but no serious results need follow from this source, as will be shown later.

Some makers prefer to make the collars of bronze instead of steel, but, with ordinary care, steel collars will not rust, and this is their only objectionable feature, while bronze is very subject to corrosion, especially in contact with grease or oil, and, being generally quite soft, is not nearly as desirable as high steel.

THE SOURCES OF ERROR IN PRECISE LEVELING.

1. Introductory.

It is proposed here to show the many sources of error to which the process of leveling is subject, and to demonstrate methods of determining them when they are sufficiently constant to make such determination possible.

As is readily seen, these errors are not all of an accidental nature, and some of them do not depend either on the instrument or the observer.

The variations in gravity at different points and elevations on the earth's surface and the attraction of the sun and moon are constant sources of error, but these, while they may be considered measurable and should enter into a discussion of this kind, are nevertheless of minor importance to the instrumental errors. These latter, as will be shown later, may be eliminated by proper methods and careful work, leaving as the most dangerous errors those which are caused by rapidly changing temperature and atmospheric conditions.

All the foregoing sources of error have been classified in a manner appearing most logical and natural, and while much that is said is not new, yet a great deal of this work is original and is considered as valuable in throwing light on many difficulties previously attributed to erroneous causes. The writer has aimed to discover, by careful study and research, all the errors to which the process of leveling is subject. Whether or not this aim has been materialized remains for future investigation to prove.

2. Effect of the Spheroidal Shape of the Earth on Long Level Lines.

a. Force of Gravity.—The direction of the plumb line at a point on the earth's surface is the resultant of the force of gravitation and the centrifugal force caused by the earth's rotation. Since the earth is an ellipsoid it follows that both gravitation and centrifugal force change their relative values for different points on the earth, and thus affect the resultant which governs the direction of the plumb line.

"The attraction which the earth exerts upon a body at its surface is the sum of the partial attractions which each part of the earth exerts upon the body, and the resultant of all these attractions may be considered to act from a single point—the center. Hence, if the earth were a perfect sphere, a given body would be equally attracted at any point of the earth's surface. The attraction would, however, vary with the height above the surface."*

In order to compare the force of gravity for different points and different elevations, it should always be corrected to correspond to sea level.

Since the force of gravity is inversely proportional to the square of the distance from the earth's center. and calling g_o this force at mean sea level, g' the force of gravity at an elevation h in free air above sea level, and R the radius of the earth, then

$$\frac{g'}{g_o} = \frac{R^2}{(R+h)^2} = 1 - \frac{2\,h}{R} + \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

For a point on a high plateau of elevation h above mean sea level, the force of gravity is affected by the mass of this plateau and becomes g''. If δ denotes the density of the material of the plateau, δ_m the mean density of the earth, $\varDelta g$ the effect produced by the mass of the plateau on the point h, exclusive of the attraction produced by the earth, and k^2 a constant, then $\varDelta g = 2 \pi k^2 \delta h$ (nearly).*

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* Ganot's Physics, 1883, Art. 82, p. 66.

The attraction of the earth alone (using the same constant k^2) is

$$g_o = \frac{4}{3} k^2 \frac{\pi \delta_m R^3}{R^2} = \frac{4}{3} k^2 \pi R \delta_m \dots\dots\dots\dots\dots (2)$$

The ratio $\frac{\delta}{\delta_m}$ is generally about $\frac{1}{2}$, as the density of the interior earth is about twice that at the surface, hence

$$\frac{\varDelta g}{g_o} = \frac{3 \delta h}{2 \delta_m R} = \frac{3 h}{4 R} \dots\dots\dots\dots\dots\dots\dots\dots (3)$$

But the force g_o corrected for the elevation h, without regard to the mass of the plateau, would be, from Equation (1),

$$g' = g_o \left(1 - \frac{2 h}{R}\right) \dots\dots\dots\dots\dots\dots\dots\dots (4)$$

Hence, since $g'' = g_o + \varDelta g + (g' - g_o)$, the actual attraction g'' found from Equations (3) and (4) is

$$g'' = g_o \left(1 + \frac{3 h}{4 R} - \frac{2 h}{R}\right) = g_o \left(1 - \frac{5 h}{4 R}\right) \dots\dots\dots (5)$$

In applying the foregoing to a revolving ellipsoid like our earth, other theories are involved which are considered in the following.

The foregoing equations apply, strictly speaking, only to a sphere, but, within knowable limits, they also apply to an ellipsoid, provided allowance is made for the change in direction of the gravity forces resulting from the latter shape, in which the forces no longer intersect in the center of the mass, and, for a general assumption regarding distribution of mass, these forces cannot be assumed normal to the surface of the ellipsoid.

Since, according to the Kant-Laplace theory, the earth is an ellipsoid of revolution, produced from a fluid or semi-fluid mass, by the influence of attraction and centrifugal force, it follows that the resultant of all the forces acting at a given point of the earth's surface must be normal to the surface at the given point.

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* See Helmert, Höhere Geodesie, II, pp. 142 and 164.

The mass attraction g', of the ellipsoid Fig. 11, on a point p of its surface, may be resolved into two components G and Q; the former, being the larger component, is directed toward the center of the earth at O, and the latter is normal to G at p.

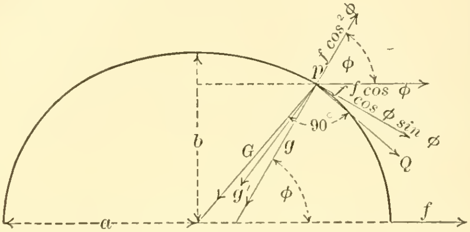

FIG. 11.

The centrifugal force at the equator is $f = a\ v^2$, in which v is angular velocity. For a latitude ϕ this force becomes $f_\phi = a \cos \phi\ v^2 = f \cos \phi$. This centrifugal force may also be resolved into the component $f \cos^2 \phi$, normal to the surface at p, and the tangential component $f \cos \phi \sin \phi$, the latter coinciding very nearly in direction with Q. The resultant of the gravity and centrifugal forces at p will then be g, which makes a small angle with g' and the angle ϕ with the equator. In other words, g is normal to the ellipsoid at p and makes the angle of the latitude with the equator.

Hence, it follows that g, the force or acceleration of gravity, at p, is proportional to $\sin^2 \phi$* as expressed by the formula

$$g = 9.7800\ (1 + 0.005310 \sin^2 \phi) \text{ m. per second} \ldots\ldots\ldots (6)$$

For latitude 45° this becomes

$$g_o^{45} = 9.7800\ (1 + 0.002655) = 9.80597 \text{ m. per second at sea level} \ldots (7)$$

By substitution in (6) for $\sin^2 \phi = \frac{1}{2}\ (1 \cos 2\ \phi)$ and combining (6) and (7) then

$$g = g_o^{45}\ (1 - \beta \cos 2\ \phi) \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

in which g_o^{45} at sea level $= 9.80597$ m. and $\beta = 0.002655$, a constant.

For any other point in free air and at an elevation h, Equations (1) and (8) give:

$$g = g_o^{45} \left(1 - \beta \cos 2\ \phi - \frac{2\ h}{R}\right) \ldots\ldots\ldots\ldots (9)$$

and for a point on a high plateau of elevation h, Equations (5) and (8) give:

$$g = g_o^{45} \left(1 - \beta \cos 2\ \phi - \frac{5\ h}{4\ R}\right) \ldots\ldots\ldots\ldots (10)$$

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* See Helmert, Höhere Geodesie, II, pp. 241 and 609.

b. Dynamic and Orthometric Heights on the Earth's Surface. –The elevation of a point h above sea level, determined by direct measurement on a vertical line, gives the orthometric height of that point.

The dynamic height of this point is represented by the work required to raise a unit mass through the height h.

Since the force of gravity varies at different points on a meridional plane, as represented by Equations (9) and (10), it follows that the amount of work required to raise a unit mass through the orthometric height h, at different points on a meridian, will vary inversely as the force of gravity at these points. Calling g_1 and g_2 the forces of gravity for two points on the ellipsoid in latitudes ϕ_1 and ϕ_2, respectively, and h_1 and h_2 the orthometric heights corresponding to equal dynamic effects at the two points, respectively, then the following relations must exist:

$$g_1 h_1 = g_2 h_2 \text{ or } \frac{h_1}{h_2} = \frac{g_2}{g_1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Now, from Equation (10),

$$g_1 = g_o^{45}\left(1 - \beta \cos 2\,\phi_1 - \frac{5\,h_1}{4\,R}\right) \text{ and } g_2 = g_o^{45}\left(1 - \beta \cos 2\,\phi_2 - \frac{5\,h_2}{4\,R}\right)$$

from which

$$\frac{g_2}{g_1} = \frac{h_1}{h_2} = \frac{1 - \beta \cos 2\,\phi_2 - \dfrac{5\,h_2}{4\,R}}{1 - \beta \cos 2\,\phi_1 - \dfrac{5\,h_1}{4\,R}} = 1 - \beta\,(\cos 2\,\phi_2 - \cos 2\,\phi_1) \text{ nearly.}$$

$$= 1 + 2\,\beta \sin\,(\,\phi_1 + \phi_2\,)\, \sin\,(\,\phi_2 - \phi_1\,).$$

Calling ϕ the mean latitude between the two places and L the meridional distance or difference in latitude measured in kilometers, then

$$\sin\,(\phi_1 + \phi_2) = \sin\,2\,\phi$$

and $\sin\,(\phi_2 = \phi_1) = \frac{L}{R} \cos \left(\frac{\phi_2 - \phi_1}{2}\right) = \frac{L}{R}$ nearly, since $\frac{\phi_2 - \phi_1}{2}$ is generally a very small angle and its cosine nearly equal to one. Hence

$$\frac{h_1}{h_2} = 1 + 2\ \beta\ \sin\ 2\ \phi\ \frac{L}{R} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

$$\text{or}\quad h_1 - h_2 = 2\ \beta \sin\ 2\ \phi\ \frac{H\,L}{R} \text{ nearly} \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

in which H = mean elevation of the two points above sea level. The factor $H\,L$ (see Fig. 12) then becomes equal to the projected area of the elevation or plateau (upon which the two points h_1 and h_2 are situated) upon a middle meridional plane. Calling this area $HL = A$ and substituting for $\beta = 0.00265$ and $R = 6\ 370\ 000$ m. in Equation (13), then

$$h_1 - h_2 = 0.832\ A \sin 2\ \phi \ldots\ldots\ldots\ldots\ldots\ldots (14)$$

If A be given in square kilometers, in Equation (14), $h_1 - h_2$ will be in millimeters.

Equation (14) then represents the orthometric error produced by the dynamic effect of the earth on the plumb line in passing between points ϕ_1 and ϕ_2 at a mean level H above sea level. It will be seen that this error is confined to meridional distance alone, since a section of the earth parallel to the equator is always a circle and accordingly the force of gravity is constant for a given latitude. This would be true for any imaginary sea level above the present level.

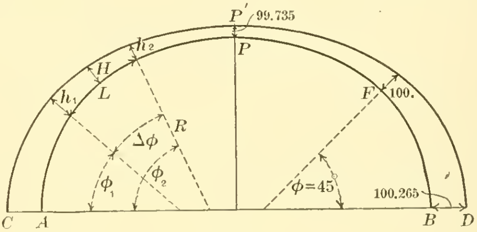

FIG. 12.

Considering $A\ P\ B$ (Fig. 12) the present sea level, and then supposing that this level were raised to a spheroidal surface $C\ P^1\ D$, as in the case of a flood, the following conditions will be found to exist:

From Equations (8) and (11) it is seen that equal dynamic heights at the points B (equator), F (for $\phi = 45°$) and P' (at pole), will bear the ratio of

$$B : F : P' = 100.265^m : 100.000^m : 99.735^m.$$

Hence such a new water level would not form a concentric curve with the present spheroid, but would have the shape indicated in Fig. 12. This leads to the following conclusion as regards the gravity effect on absolute elevations as referred to mean sea level.

It is readily understood that in a line of precise levels run along the earth's surface on a meridian, and at sea level, from the equator to the pole, the closure with sea level at the pole would be zero. But if a return line were run from the pole to the equator, taking the path indicated by the line $P'\ D$ (Fig. 12), and then closing back on the point B, the complete loop, even if free from all error, would close with a spheroidal error of $99.735 - 100.265 = -0.530$ m.

In a similar manner Equation (14) then represents the error introduced by gravity into any line of levels run between points on latitudes ϕ_1 and ϕ_2, or through a meridional arc ϕ (in degrees), in which A represents the projected area of the level profile upon a middle meridional plane, taking the mean sea level for the axis of ordinates. Also, $h_1 - h_2$ represents the gravity error, and for a point north of the starting point this error is positive or additive to the elevation of the terminal point to give true sea level. The error is negative for a point south from the starting point.

While the above derivation is not rigid and the resulting Equation (14) is only approximate, it is believed that the accuracy attained by its use is quite within practical limits.

It should be noted that the local deflection of the plumb line as might be caused by a mountain, when leveling up on one side, is not considered in the foregoing.

3. Disturbing Influence of Differential Attraction of the Sun and Moon on the Direction of Gravity, and Its Effect on Spirit Leveling.

The discussion of this subject is abstracted from the Report of the Coast and Geodetic Survey, 1887, p. 196, from the article of the above title by Charles A. Schott, Assistant.

The following formulas for the disturbance in direction of gravity by the action of the sun or moon as a result of the diurnal variations in position of these luminaries with respect to any point of the earth's surface, were the result of an investigation by Dr. F. R. Helmert*:

Let M = Mass of the sun or moon;
$M_\odot$ = Mass of the earth;
p = Horizontal parallax of the luminary;
z = Zenith distance of the luminary;
A = Azimuth of the luminary counting from south around by west;
α = Azimuth of the level line counting from south around by west;
l = Length of a single shot, in meters;
P = The disturbing effect on the direction of gravity;

then
$$P = \frac{3\, M \sin^3 p}{2\, M_\odot \sin 1''}$$

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* Höhere Geodesie, Vol. 2, Chapters 5 and 7; Leipzig, 1880–84.

and the southerly deviation of the disturbed zenith will be

$$S = -P \sin 2z \cos A,$$

and the westerly deviation will be

$$W = -P \sin 2z \sin A.$$

In consequence of the disturbed direction of gravity, the position of the level surface at any point on the earth will be changed, and this will affect the pointing of a level.

If, for instance, a level line is run in a southwesterly direction the fore sights will be depressed in consequence of the disturbed vertical by the angle

$$\gamma = S \cos \alpha + W \sin \alpha = -P \sin 2z \cos (A - \alpha) \ldots\ldots (1)$$

and the correction to the rod readings will be $+ l\gamma$ on the fore sight and $l\gamma$ on the back sight. Hence, the correction to difference of elevation will be

$$2\, l\, P \sin 2z \cos (A - \alpha) \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Introducing numerical values in the above expression for P, the maximum effect for the moon becomes $P = 0.0174'' = 0.000\,000\,083$ in arc, and for the sun $P = 0.0080'' = 0.000\,000\,043$ in arc. Thus, for any one instrumental setting this effect is altogether insensible, but it may become sensible by accumulation in extended lines of levels.

Let it be supposed that the sun and moon are in the equator, or have zero declination, and that the leveling is done in the northern hemisphere, then in the expression (2) z in the first quadrant will be accompanied by A in the first or fourth quadrant, and z in the second quadrant will be accompanied by A in the second or third quadrant. Hence, in leveling from north to south, or for $\alpha = 0$, this expression will always be positive, whereas for an east and west line ($\alpha = 90^\circ$) a change in sign may take place and compensation will, to some extent, diminish the effect under consideration. The circumstance that the luminaries assume different declinations does not, in the main, alter the general effect.

For level lines in a north and south direction there will remain some average effect on the resulting difference of elevation which cannot be eliminated by a repetition of lines. However, for an east and west line the lunar effect may be eliminated and the solar effect be considerably diminished. The actual effect on a line may not exceed two-thirds the maximum value and will generally be less than one-half of the same.

A line of levels, 100 km. long, running due south, might incur a maximum producible error from the moon of + 8.3 mm., though the actual error would probably not exceed 4 or 5 mm. The sun alone would produce about half as much as that estimated for the moon.

For a duplicate (direct and reverse) line of levels, 1 000 km. long, in an east and west direction, during the summer months, running forenoons always westerly and afternoons always easterly, Dr. Helmert estimates that the results of the two levelings may differ, in consequence of differential solar attraction, by as much as 87 mm., although the mean result would not be affected.

Whether or not such an effect could be demonstrated with the present methods and instruments seems somewhat doubtful, as it would appear that so small an error as 0.08 mm. per kilometer would be entirely concealed by the existing probable uncertainties of leveling.

However, the following observations made by the writer in 1898–99, while running a duplicate line of precise levels along the St. Lawrence River, show something of this kind.

The general direction of the line was from northeast to southwest, over a distance of about 207 km., run in 167 separate stretches, during August, September, October and November, 1898, and May, 1899.

Table No. 3 shows the number of closures of each sign for the four combinations of direct and reverse lines run forenoons and afternoons.

TABLE No. 3.

	Stretches Run.							
	Direct, A. M. Reverse, P. M.		Direct, P. M. Reverse, A. M.		Direct, A. M. Reverse, A. M.		Direct, P. M. Reverse, P. M.	
No. of stretches........	30	25	17	23	19	14	18	21
Sign of closure.........	+	—	+	—	+	—	+	—
Percentage	82% minus.		74% plus.		73% minus.		85% plus.	

Of the 167 stretches, 84 closed with a plus error and 83 with a minus error, showing that this effect was practically eliminated in the entire work by properly dividing up the work between forenoons and afternoons. This division was as follows: 88 direct lines run A. M.; 79 direct lines run P. M.; 73 reverse lines run A. M.; and 94 reverse lines run P. M.

The stretches tabulated in the third and fourth combination in which direct and reverse lines were run in the same half of the day vitiate to some extent the law sought, because it there depends on which one of a pair of lines was run first. As, for instance, of the 33 lines run direct and reverse in the forenoon, if 16 were run direct in the earlier part of the forenoon, and 16 were run reverse in the earlier part, then there should be an equal number of errors of each sign. The same would apply to lines run in both directions in the afternoon.

Again, the work done in clear weather, which generally prevailed, involves a much larger accidental error than is found in work done on cloudy days, and this again vitiates the distinct manifestation of a definite law. However, the general result of the first and second combination in Table No. 3 exhibits a fair indication of the effect here considered.

Hence, it might be concluded that, for an east and west line, this error can be eliminated by dividing the work equally between the two halves of the day, while for a north and south line the error would not be manifested by the work, although it might exist to the same extent.

However, it is quite likely that this is merely a seeming detection of errors from the source here considered, and that the real error is one due to temperature, as discussed further on.

4. Errors of the Level Tube.

a. Parallelism of the Level Tube with the Vertical Plane through the Telescope Axis.—When the level tube is not parallel to the vertical plane through the telescope axis a slight lateral tilting of the striding level will cause the bubble to run to one end of the tube, and this would introduce an error of pointing unless the level tube were always placed with its axis in a horizontal plane, which is impracticable. There must always be a slight play laterally to permit of readily removing the tube from its supports and reversing it. However, the play necessary for this purpose is very small.

Parallelism of the level tube with the vertical plane through the telescope axis can be readily established by adjustment with the horizontal adjusting screw, and should be continued until a lateral tilt of the level tube no longer displaces the bubble. This adjustment is called the lateral adjustment of the level tube and is not likely to change much in a well-constructed instrument, but the adjustment should be tested occasionally. It is very important that a level should be free from error of this kind, because the observations cannot be made to eliminate such errors, and it is one of the few instances in which the accuracy of the work depends absolutely on the adjustment of the instrument.

b. *The Horizontality of the Level Tube.*—This is indicated by the position of the bubble with respect to the graduation on the glass tube of the spirit level. This graduation may be continuous from one end of the tube to the other, or it may extend from the center of the tube toward its ends, which latter style is generally more convenient, although the first always identifies the end of the tube read. Still, this is quite unnecessary, since the bubble ends can be identified in other ways, and readings taken from the center outward require no reduction, and are, therefore, preferable.

The striding level, which should always accompany a precise leveling instrument (see Fig. 7), is so arranged that it may be read either in a direct or reversed position, and the construction permits of adjusting the inclination of the level tube to the points of support on the telescope collars. This may be done by clamping the instrument, after it has been made approximately level by the small spirit levels, and then reading the striding level in its direct and reversed position. One-half the discrepancy thus obtained is then taken up on the vertical adjusting screw at the chamber end, and the other half is corrected by the micrometer on the wye-cradle. This operation should be repeated until the bubble remains in the center for both direct and reversed positions. When this has been accomplished, the level tube is parallel to the axis of the telescope, the lateral adjustment having first been made and the telescope collars being exactly equal. The effect of unequal collars will be treated later.

While this adjustment would generally eliminate the error of horizontality of the level tube, it is found that no very sensitive level tube will hold this adjustment very long, and it often happens that the first two or three reversals of a level may show perfect adjustment, and a fourth reversal may indicate a considerable error. The converse also frequently occurs, especially if the adjustment is tested soon after removing the level from the box.

Many disturbances of the level tube will be caused by fine particles of grit on the telescope collars, sudden changes in temperature and wind, cooling effect of rain drops, should any fall on the level, and passing clouds which change the direct and reflected rays from the sun. All these are ever present to affect the horizontal adjustment of the level tube, and it is altogether out of the question to place any reliance on a level holding this adjustment. It is not a question of quality and fineness of the instrument; on the contrary, the more sensitive the level the more readily will its adjustment be affected, and this is no detriment, as many have claimed, but is a positive safeguard, and keeps the observer constantly informed of all deleterious influences that may exist.

The effects of temperature and length of bubble have already been discussed. Suffice it to say here that the variations in curvature of a level tube from temperature effect vitiates the use of the level for any measurements in which the value of this curvature is involved, while it does not in any way affect the utility of the level in the determination of the horizontal when the bubble is always brought to the center. This is one of the prime reasons why the older method of reading the bubble in any position was less accurate than the method of taking readings with the bubble in the center.

It follows, then, that no reliance should be placed on the capability of a level tube for holding its horizontal adjustment, and hence there is no possibility of measuring this error and applying a correction therefor to the observations. The only rational elimination of this error can be accomplished by taking observations for each sight with the level tube direct and reversed. The mean of such a pair of sights, taken in quick succession, always eliminates the bubble error, whatever its amount may be. Hence, the observer need only keep the level adjustment within reasonably small limits, and carefully avoid dust between the contact points of the level tube and the telescope collars; then, repeated pointings, with level tube direct and reversed, will always eliminate the bubble error.

c. The Parallax between the Reflected Images of the Bubble and the Level Tube Graduation.—This, as seen in the mirror, constitutes an error in level pointings which is apparent from the diagram, Fig. 13.

The bubble *a*—*b*, shown in the center of the level tube and reading 15 at each end, is seen at *a*′—*b*′ in the mirror *m*—*n*, while the image of the graduation is seen projected upon a different plane, thus giving rise to a parallactic error. In the diagram, the mirror image would show the eye end of the bubble at 14.1 divisions and the object end at 15.7 divisions from the center of graduation. The mean error due to parallax would then be 0.8 division.

Thus, while there may be considerable error in the apparent position of the bubble as seen in the mirror, this error remains constant so long as the inclination of the mirror remains the same and the eye is always in the same position. Both these requirements are practically fulfilled. Hence, if back sights and fore sights are equal, this error is eliminated. It is this difficulty which is solved in such a complicated manner by the prismatic combination attached to the French precise level, Fig. 2, Plate XXXV, without any urgent necessity.

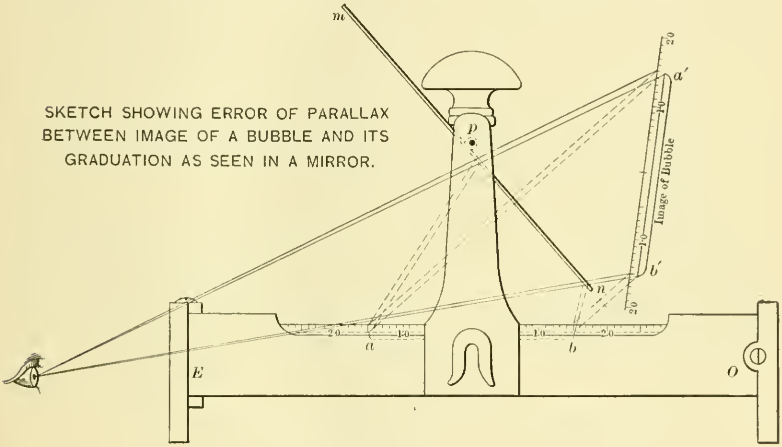

SKETCH SHOWING ERROR OF PARALLAX BETWEEN IMAGE OF A BUBBLE AND ITS GRADUATION AS SEEN IN A MIRROR.

FIG. 13.

With a little study of the diagram, Fig. 13, it is readily seen that for a constant position of the eye, a certain inclination of the mirror will make the parallax of the bubble ends equal and opposite, thus affecting only the apparent length of the bubble, as seen in the mirror, but not its horizontalism. This angle is readily found, and small set-screws provided on the mirror or mirror-frame will limit the motion of the mirror to the desired angle (see Fig. 7). The eye can, with little practice, be placed near enough to the same position to reduce this error, due to parallax, to insignificance, and thus make the mirror the simplest and best device for viewing the bubble while taking the rod reading. With little practice the observer can learn to observe both the rod and the bubble simultaneously, an advantage which cannot be overestimated.

Another feature in favor of the mirror, as applied to high-grade levels, is that the less the curvature of a level tube, the less will be the error due to parallax, supposing that the mirror is not adjusted. Thus, suppose the parallax for a given case to amount to 0.5 bubble division, then if the level have a curvature of 10 seconds per division this would cause an error of 5 seconds in pointing, while for a 2-second level tube the error in pointing would be only 1 second. Hence, a poorly adjusted mirror might prove serious on a common coarse level, while on a very sensitive level the error might be inappreciable.

d. The Error of Pointing.—As influenced by the sensitiveness of the level, this is an important question in precise leveling, and many are of the opinion that the accuracy of work attained with a level of 6 to 10 seconds curvature is equal or superior to that attainable with a 2-second level. However, this assertion is not sustained by practice or theory, and is largely the result of prejudice and lack of experience on the part of the person holding such views.

An illustration of the relation between curvature and error of pointing of level tubes is given by the experiments of Reinherz in Table No. 4, in which the length of one division of the bubble is 2 mm. This applies to a large number of readings, while a single reading may readily be in error by ± 0.1 division.

TABLE No. 4.

Sensitiveness of tube.	MEAN ERROR	
	of centering bubble.	of reading bubble.
2.7 seconds of arc.	± 0.135 seconds = ± 0.045 div....	± 0.27 seconds = ± 0.09 div.
4.5 "	0.18 " 0.036 "	0.315 " 0.063 "
9.0 "	0.27 " 0.027 "	0.45 " 0.045 "
18.0 "	0.36 " 0.018 "	0.765 " 0.036 "
27.0 "	0.45 " 0.013 "	1.08 " 0.036 "
54.0 "	0.63 " 0.009 "	1.44 " 0.027 "

From these figures it is seen that the accuracy attainable in centering the bubble is far greater than that attainable by reading the bubble in any position and making the reduction to the center. This again proves the desirability of observing always with the bubble in the center, in preference to reading the bubble and reducing to the center.

Accordingly, for a 9-second level, the mean error of centering would affect a rod reading for a distance of 100 m. by ± 0.5 mm. which is greater than the permissible error of closure for a stretch of 100 m. For a level tube of 2.7 seconds curvature, the mean error for the same length of shot would be ± 0.1 mm., which is about equal to the error of estimation. Hence, while the coarser level might enable one to close a stretch with a comparatively small error of closure, such fact would only indicate an accidental compensation of errors, but would not be a measure of the excellence of work equally producible with such a coarse level. With the finer level, an accidental cumulation of errors might cause a comparatively wide closure on a given stretch, but this would then be the most unfavorable result possible and would probably still remain within the assigned limits for good work.

The length of the bubble is also a factor in the accuracy of pointing, as was previously shown, and should be considered in this connection. A short bubble creeps very slowly and does not indicate the slight and sudden changes which immediately start a long bubble. A similar effect is produced by certain conditions of damp, cold weather and by levels of about 6 seconds curvature and over. A very sensitive level can be forced to the center by the micrometer and a reading may be taken at once, while in a coarser level the bubble must be allowed sufficient time to stop creeping before the reading can be taken. Hence wind and other disturbing influences produce comparatively more annoyance when working with a coarse level.

5. Errors Pertaining to the Telescope.

a. The Reticule Error.—In a properly adjusted level, the reticule should be sharply seen through the eyepiece. There should be no blurred effect at any point of the threads within the field of distinct vision, and the threads should show no parallax when the eye is moved slowly up and down in front of the eyepiece. When the eyepiece lenses and the reticule are all perpendicular to the telescope axis, there will be no difficulty in preventing all errors from this source by properly focusing the eyepiece on the threads of the reticule.

When the horizontal threads of the reticule are not absolutely horizontal, the readings taken at different points of these threads may differ materially, and, to prevent errors from this source, the horizontal threads must always be read exactly at the intersection points with the vertical thread. As an additional safeguard, the horizontality of the threads should be made adjustable by a simple adjustable stop device to check the movement of the telescope in its cradle at exactly the desired horizontal position when the telescope is moved in azimuth. This adjustment, properly made for the normal and inverted position of the telescope, will prevent all errors from lack of horizontality of the threads.

The thread interval should be as small as possible and yet permit of making distance determinations with an accuracy of at least one in a thousand. For a magnifying power of 50 diameters a thread interval of 1 in 200 will satisfy this requirement. When threads are widely separated, they will not permit of sharp focusing on all threads simultaneously, and the widely divergent rays will traverse strata of air of different temperature, density and humidity. Many serious errors may result from a slightly excessive thread interval.

The thread interval is not absolutely constant, and, strictly speaking, is dependent on the temperature of the reticule frame. If the reticule be of brass, the distance determination should be reduced to a standard temperature by using the coefficient of expansion for brass. However, the distance determination need only be relative between back and fore sights, and, as the change in temperature would not be sufficiently great to affect this relation, it may be neglected. It is valuable, however, in making repeated determinations of the value of a certain thread interval, to note the different results for different temperatures.

The most serious error in connection with the reticule is its position with reference to the axis of the telescope. The level tube is the starting point to which the direction of the telescope must be referred. Hence, the center of the reticule (formed by the intersection of the mean horizontal thread with the vertical thread) should be on the axis of the telescope, or axis of collimation, which can be accomplished by adjustment of the reticule, provided the optic center of the objective lens is also on this axis, a condition which is rarely ever fulfilled by the maker. Since the objective is fixed in the telescope tube no adjustment is possible, hence what is ordinarily called collimation adjustment does not generally accomplish the object implied by this term. If it were possible to bring the line of sight into coincidence with the telescope axis, as defined by the centers of the collars, by adjustment of the reticule alone, then the commonly applied term "collimation adjustment" would be correct, but this not being the case it is better to adopt the more precise term "thread or reticule adjustment," which will be used in the following.

When the line of sight does not concide with the telescope axis, then the former is inclined to the position indicated by the bubble, and the error resulting from such inclination can only be eliminated by repeated readings taken with the telescope normal and inverted, always keeping the bubble in the center. This is true whether or not the collars of the telescope are equal.

The reticule might be so adjusted that for a certain length of sight the readings of the middle thread would be the same for telescope normal and inverted, but this adjustment would not hold good for any other length of sight unless the optic center of the objective lens be in the axis of the telescope. Hence, the thread adjustment alone will not generally eliminate errors of collimation, but repeated readings in normal and inverted positions of the telescope will effectually eliminate collimation errors of whatever magnitude.

With this method a very good line of levels can be run by reading only one of the extreme threads; the mean of the two readings will always agree closely with the mean of the mean thread readings. This subject will be more clearly represented in the following in connection with the mounting of the lenses.

In closing this subject it should be noted that the thickness of the telemeter threads is a very important matter in the attainable accuracy of readings at long distances. The threads should be the finest possible, otherwise the length of sight must be limited to suit the quality of the threads.

b. Errors Due to Defective Mounting of the Lenses.—As has been stated previously, a slight eccentricity in the mounting of the eyepiece lenses produces no deflection in the line of sight, though it changes the optical axis of the telescope. If the eccentricity is bad, or the axis of the lens is not parallel to the line of sight, the definition may be poor, and thus affect the sharpness of the extreme threads, or even prevent obtaining a sharp image simultaneously on all threads. This is then a serious defect which must be remedied by the maker.

Displacements of the objective lens are far more serious, and affect the line of sight by the amount of such displacement. The line of sight is not affected by oblique mounting of the objective, but this fault will interfere with the definition, as in the case of eyepiece obliquity.

Any lateral displacements of the eyepiece or objective may be readily discovered by focusing on a distinct object and then carefully revolving the telescope on its horizontal axis. The image and the threads (even when the thread adjustment is perfect) will appear to move in the arc of a circle about the axis of the telescope.

It is easily seen that for a telescope, with laterally displaced objective, the thread adjustment when performed does not bring the line of sight into coincidence with the axis of the telescope (collimation axis). When the center of the reticule is so adjusted that it coincides with an image for both normal and inverted positions of the telescope then the center of the reticule, the optic center of the objective and the object sighted on are in a straight line called the line of sight, but this line is neither parallel nor coincident with the telescope axis except when the thread adjustment was performed for an object at an infinite distance and the optic center of the objective is on the axis of the telescope. Hence, for thread adjustment on an object at a finite distance, D, and the objective not truly mounted, the line of sight will be inclined to the telescope axis by an angle ε, expressed in seconds by the formula,

$$\varepsilon = \frac{a}{D \sin 1''}$$

in which a is the lateral displacement of the optic center of the objective from the axis of the telescope. Thus, for a displacement $a = 1$ mm. and thread adjustment performed for the usual distance $D = 50$ m. the inclination ε becomes 4.1 seconds or 0.02 mm. per meter of distance.

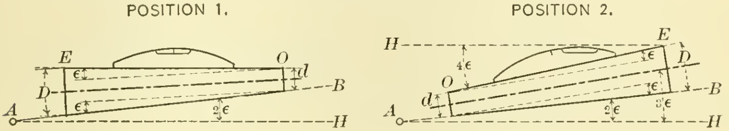
While this displacement a is generally quite small, yet the effect produced thereby on the line of sight should not be overlooked.

This error should be eliminated in the observations in the manner indicated for thread errors, viz.: by reading with telescope normal and inverted.

c. *Movement of the Eyepiece Slide.*—This is frequently very defective, even in high-grade levels, and constitutes a serious detriment in any instrument, because any obliquity of motion of the eyepiece with respect to the line of sight affects the thread adjustment, since the reticule moves with the eyepiece. The same difficulty is encountered with telescopes in which the objective is made to slide, as in Fig. 2, Plate XXXVI.

When the sliding tube (be it eyepiece or objective) is short, its motion may be very irregular, a circumstance rendering the telescope almost worthless for precise work. The sliding tube should be as long as is permissible by the telescope tube, and all lateral motion should be prevented by spring pressure, as shown in Fig. 10. With such an arrangement the direction of motion will be a straight line even if it does not coincide with the axis of the telescope, and the repetition of readings in normal and inverted positions of the telescope will again eliminate any error caused in the thread adjustment as a result of inclined motion of the eyepiece or objective.

A method for determining the regularity in the eyepiece movements will be given under the head of instrument constants.



(a) (b)

Fig. 14.

d. Error Resulting from Inequality of the Telescope Collars.—Any existing inclination in the line of sight, not explained in the foregoing, and inherent in the instrument itself, must be caused by unequal telescope collars. The commonly accepted method of determining the inequality will be briefly given, while no further use will be made of this method, owing to its many imperfections, which will be presently demonstrated.

The common method of determining the inequality of the collars is illustrated in Fig. 14, and the operation consists in setting up the instrument on a rigid stone pier, and, after leveling up carefully, the limb of the instrument is tightly clamped and the bubble is read for the telescope pointing direct, as in Fig. 14*a*. The level and the telescope are then reversed together on the cradle supports, as in Fig. 14*b*, taking care not to jar the instrument. When the bubble has become quiet a second reading is taken. This constitutes one determination, as indicated in the following example, where the bubble is read from the center:

The figure shows that the angular inclination measured by the two positions of the bubble (whether in adjustment or not) is four times the angle between the axis of the collar and the elements of the cone enveloping the collars. The line $A\ B$ represents the position of the cradle supports, which remains constant during the experiment, and Position 1 makes the upper element of the cone horizontal, or at least with the bubble in the center, while in Position 2 the bubble indicates a displacement toward the larger collar equal to four times the error in axial pointing of the telescope or twice the collar inequality.

Example.

Position 1.		*Position 2.*	
Bubble readings:		Bubble readings:	
right-hand end.	left-hand end.	right-hand end.	left-hand end.

$$\underbrace{16.5 \qquad\qquad\qquad 16.5}_{0} \;\ldots\ldots\text{center of bubble at}\ldots\ldots\; \underbrace{13.1 \qquad\qquad\qquad 20.1}_{-3.5}$$

or $4\ \varepsilon = 0 - (-3.5) = +\ 3.5$ or $\varepsilon = +\ 0.875$ bubble divisions.

The value of one division of the bubble being 6.5 seconds, $\varepsilon = 0.875 \times 6.5 = 5.688$ seconds. The mean of twenty observations gave $\varepsilon = 5.90$ seconds $= 0.0276$ mm. per meter.

This method assumes that the collars are perfectly circular, that the level tube actually indicates the direction of the topmost element of the enveloping cone of the collars, and that the points of contact between each collar, the level tube and the cradle supports, are on the arc of the same circle; an assumption which is rarely true of a new instrument and never true of an old one. The extent to which the foregoing determination is erroneous will now be shown.

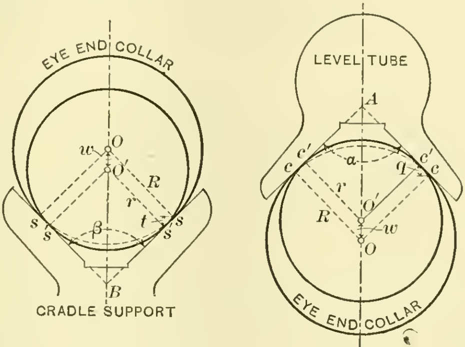
The telescope does not rest on the lowest element of the collars, but on the points s, Fig. 15a, because the two collars penetrate the angular aperture of the forked cradle supports unequally. Hence, the level tube pointing does not involve the true inclination of the upper elements of the cone formed by the collars, with respect to the points of support s. The same is true of the contact points c between the level tube and the collars, Fig. 15b.

It would generally be assumed that this error is beyond the limits of measurement for the slight inequality usually existing between the collars, and could, therefore, be neglected. The case, however, demands investigation.

Using the dimensions as indicated in Fig. 15*a*, and calling ε the correction for collar inequality as previously determined by the common method, w, the actual inclination of the telescope axis resulting from collar inequality, and t the vertical distance between s' and s, then the following approximate relations may be used to determine w and t:

$$w = \varepsilon + t \text{ and } w = \frac{t}{\sin \frac{\beta}{2} \cos \frac{\beta}{2}}$$

Thus, for the Buff and Berger Level, No. 2768, $\varepsilon = 0.0276$ mm. per meter, and $\beta = 90°$; hence, by substituting and solving, $t = 0.0268$ and $w = 0.0544$ mm. per meter.



(*a*) (*b*)

FIG. 15.

By making allowance for the fact that in the determination of ε by the ordinary method, this quantity is involved four times in the reversal of the telescope in the cradle supports, while t enters only twice, the inclination for telescope axis resulting from inequality of collars should be $\varepsilon + 2\,t = 0.0812$ mm. per meter.

The effect of the collar inequality on the contact points of the level tube is opposite to that produced by the cradle supports, and is eliminated when the level tube is read always in the same position relatively to the telescope. However, when the level tube is read direct and reverse the actual inclination of the telescope axis is smaller than the above value w by the amount $\frac{q}{2}$, found from Fig. 15*b*, by a similar process of reasoning as applied to Fig. 15*a*.

For $\alpha = 89° 30'$, t is practically equal to q and $\frac{q}{2} = 0.0134$, which, subtracted from the last corrected value, gives the final resulting inclination $p = 0.0812 - 0.0134 = 0.0678$ mm. per meter.

This is all based on the assumption that the collars are perfectly circular, and that the four contact points of each telescope collar are in a plane, normal to the telescope axis, all of which is not generally true. The worthlessness of the common method of finding the collar inequality is thus made apparent.

It is readily seen that the axial inclination of the telescope, resulting from collar inequality, is measured by the position of the level tube with respect to the collars, but bears no relation to the cradle supports *s*, except when the latter become involved by some method as the above, which is worthless because of this fact. Hence, the wear on the collars cannot be determined in any manner involving the contact on the cradle supports. Also, the accuracy required in the determination is beyond limits of calibration. To add to this difficulty, the cradle supports are never in the same planes with the level tube contacts of the respective collars, so that this question must be solved by another method.

The resultant axial inclination from unequal collars may be made constant by confining the wear of the collars on the cradle supports to a special path on each collar and never revolving the telescope on its axis without first removing the striding level, so that the wear between the level and collars is practically impossible and is independent of the cradle supports. The relation between the telescope axis and the striding level then remains constant, and any wear caused by the continual revolving of the telescope, whatever its amount, does not affect the telescope pointing as indicated by the level tube. All this is done simply by making the distance between the cradle supports different from that between the forked ends of the striding level, or by supplying two pairs of collars, one for the cradle contact and the other for the level tube. This is exactly in contradiction to past practice, because the axial inclination still existing, while it would thus remain practically constant, appeared indeterminate by any method of direct measurement with the bubble.

A very simple and extremely accurate method of determining the real inclination between the telescope axis and the striding level, devised by the writer, and considered to be a most satisfactory solution of this and a number of other uncertainties connected with the level, will be given under the head of instrument constants.

The complexity of the axial error resulting from collar inequality is made apparent by the foregoing considerations, and the disparity shown to exist between the actual conditions and the commonly accepted method of determining the inequality in telescope collars is quite sufficient to explain many of the constant errors frequently encountered in leveling operations and attributed to a great variety of causes, principally personal equation and settlement or heaving of instrument or rods. This error may, however, be eliminated by a strict equalization of back and fore sights, and hence becomes quite insignificant when the nature of the error is properly understood.

6. Errors Pertaining to the Level Rods.

a. The Error in Verticality.—This generally receives little consideration further than to prevent excessive inclination of the rods by using watchglass levels, which are frequently adjusted. However, the subject demands very careful attention.

If for some reason the rod levels are out of adjustment and the rods are not held plumb, all readings become too large, and this would produce errors when working over inclined ground. Such errors are of a somewhat constant nature and may work serious harm, hence the importance of frequent and careful tests of the rod adjustment.

b. The Errors of Temperature and Graduation.—These errors, though widely different in cause, are conveniently considered together, since both may be corrected in one operation.

Generally, the temperature effect is a constant change per degree of temperature within the limits during which work should be conducted. The same is true of errors of graduation, which are generally proportioned to the distance measured on the rod.

There are cases, however, where neither the temperature nor the graduation correction are constant, and for such rods the true length for each portion of the rod must be measured with a correct standard for all working temperatures, these values being then tabulated for use. This is the French system, wherein the rods are purposely graduated irregularly to prevent the observer from knowing what his closures are until the rod lengths have all been reduced and corrected. It is, no doubt, better policy to simplify this matter by a uniform graduation and to place a little more confidence in the integrity of the observer.

The combined graduation and temperature correction may be applied in one of two ways: By determining, by frequent comparison with a standard measure, the law for the length of the rod in terms of the standard and temperature, or by direct comparisons with a steel tape of known length.

The latter method is preferable because a steel tape is not affected by humidity and gradual changes from seasoning as is the case with wood. The law of the length of the steel tape once determined may be used almost indefinitely, while the rods are continually undergoing changes. The coefficient of expansion for pine is about 0.000004 per degree Centigrade, and the maximum changes from humidity may amount to 0.3 mm. per meter in the course of a whole summer.

The necessary thermometers and steel scale have already been described, and it will be sufficient here to show only the method of correcting this error.

The general formula for the length of a metallic scale is $1^m = 1 \pm k + \alpha\ t$ in which k is the graduation error, α the coefficient of expansion, and t the temperature in degrees above the normal.

The corrections for one meter of the tape are computed, for every degree of temperature, and these corrections are then tabulated for use.

The temperature and the measured length of one meter on each rod are recorded at the beginning and end of each stretch, and the average is taken to represent the mean rod length for the stretch. The tape correction for the mean temperature is then applied to this rod length, and the difference of elevation is accordingly corrected. When the rods are very nearly alike, as they should be, and always alternate in regular order, this method will prove very satisfactory and not at all complicated.

The past practice of applying a constant rod correction for a whole season's work is not scientific or admissible. The correction should be determined in the field by direct tape comparisons and be applied by stretches.

c. The Error of Estimation.—The smallest, or unit, graduation generally used on precise level rods is the centimeter, though a smaller unit is very necessary. Rod readings should be as accurate as the telescope pointings, which would necessitate the possibility of estimating with an accuracy of ± 0.1 mm. at a distance of 100 m. This could be attainable only with graduations as small as 2 mm. All this is on the assumption that the individual rod readings should be of the same accuracy, or excellence, as is indicated by the closure of a stretch of levels, which is not generally true because the error of estimation is a compensating error and may be large on individual shots and finally become zero for a long stretch. This is actually verified in practice.

However, it frequently happens that a stretch is only 50 m. long, and unless a single pair of sights can be taken with an accuracy of ± 0.1 mm. or less, such a stretch could not be closed with the desired exactness except by many repetitions of readings.

To show the relative value and accuracy of rod readings under various conditions it will be necessary to analyze the effect produced on the appearance of the rod by the distance at which the rod is placed from the instrument, and the position of the thread on the unit graduation.

The apparent magnitude of the unit rod graduation (generally 10 mm.) is expressed by the formula $a = \frac{0.25\, t}{l}\, m$, in which t is the unit rod graduation in millimeters, m is the magnifying power of the telescope and l the length of shot in meters. The constant represents the distance, in meters, at which an object would appear full size to the normal, naked eye.

Table No. 5 gives the apparent magnitude of unit rod graduations for different lengths of shot and magnifying power of 50 diameters, as obtained from the foregoing formula.

TABLE No. 5.

Length of shot.	5	10	20	30	40	50	60	70	80	90	100	meters.
a for t = 10 mm.......	25.00	12.50	6.25	4.17	3.12	2.50	2.08	1.79	1.56	1.28	1.25	millimeters.
a for t = 5 mm.......	12.50	6.25	3.12	2.08	1.56	1.25	1.04	0.90	0.78	0.70	0.63	millimeters.
a for t = 2 mm.......	5.00	2.50	1.25	0.83	0.62	0.50	0.42	0.36	0.31	0.28	0.25	millimeters.

The apparent thickness of good reticule threads will be 0.1 mm., or less, and this would enable the observer to estimate at least one-fourth of the 2-mm. graduation at 100 m., which, combined with the error of pointing, would bring the total error of a single reading just within the assigned limits of high-grade work.

To estimate only to the nearest millimeter on a 10-mm. graduation would be quite out of the question for a shot which is shorter than 30 m., though this would already exceed the allowable limit. For the 5-mm. graduation the desired accuracy could still be attained on a 20-m. shot, and for a 2-mm. graduation it could be expected for a 10-m. shot. When the respective shots are smaller than those just mentioned, the apparent magnitude of the various unit graduations becomes too large to permit of accurate estimations. Hence, the 2-mm. graduation is the best suited to permit of readings within the required accuracy for all shots between 10 and 100 m.

As to the comparative accuracy of estimating tenths of a division, the following considerations are offered: The 0.5 or middle point of a space can be ascertained with the greatest accuracy, while the one-third or two-thirds points are more difficult to estimate. The quarter points are quite indefinite. This circumstance is a very important factor in the science of estimating, which is often lost sight of. All estimations should be based on the half, third and quarter points, the tenths are practically guesses, if otherwise determined.

According to some experiments made by Krummer,* the error of estimating the individual tenths, calling the error on the 0.5 point unity, is as follows:

Tenths..	0	1	2	3	4	5	6	7	8	9
Error...	1.28	1.37	1.47	1.42	1.17	1.00	1.07	1.23	1.35	1.47

This again points to the desirability of estimating on the smallest possible unit in order that the error of estimation may become insignificant.

Another circumstance affecting the accuracy of estimation is found in the ever-changing illumination, and the definition of the telescope, which latter depends largely on the quality of the illumination.

The difficulty of estimating on 10-mm. graduations with an accuracy commensurate with high-grade leveling is thus clearly shown, and the advisability of adopting a 2-mm. graduation, as suggested by the design of leveling rod proposed by the writer, is made apparent.

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* Zeitschr. für Verm., 1897, p. 261.

7. Miscellaneous Errors.

a. Errors of Reading and Recording.—Misreadings may frequently occur, especially by inexperienced observers, and it sometimes happens that the recorder notes a reading erroneously. However, with experienced men errors of this class are very rare, though the possibility of introducing them into the work should be reduced to a minimum.

Various precautions are used to prevent such errors, even when made, from creeping into the work. Some of these are quite effective, and the system adopted by the writer may be regarded as almost absolute protection against errors of both kinds. At least, no stretch ever failed to close, as a result of such errors.

To prevent misreadings, the system of reading on three horizontal threads was introduced many years ago, and is still a valuable check, though it frequently happens that the erroneous reading cannot be identified except when the back and fore sights are known to have been made nearly equal. Also, on short sights, where the decimeter is the same for the three threads, it may happen that all three readings are read wrong by a decimeter. Hence, this method does not afford sufficient assurance of the prevention of misreadings, and a further precaution is necessary.

The French system, formerly used, was for the observer to take the first set of readings and then have them repeated independently by the recorder, and if both sets checked, the work was accepted, otherwise the process was repeated. However, this is slow and unsatisfactory, because the two persons would generally estimate differently on the rod, and thus introduce an element of doubt and divided responsibility.

As will appear later, the method of observing, adopted and used by the writer, necessitates two pairs of readings to eliminate instrumental errors, and incidentally this affords an almost infallible check, as the two sets of sights are independently and separately taken. When, in addition to all this, the observer trains himself not to remember any figures or readings, which is the only true scientific manner of observing, the same errors are not repeated and there remains little opportunity for an error passing undetected by the recorder.

It is also a bad practice, generally followed, to have the recorder repeat back the readings called off by the observer. It was found that this is both annoying and time-consuming and tends to create confusion and introduce errors rather than to prevent them. Absolute quiet should reign about the instrument when observations are being taken. No talking should be done except by the observer, and he should confine himself to only such utterances as are to be recorded in the notes. When a set of readings is completed the recorder signifies their correctness before the instrument is carried forward, otherwise any existing disparity must first be reconciled.

This system checks the correctness of both the recording and reading, and the order of entering the readings (as will be seen later) is such as to afford a very ready comparison of those readings which ought to correspond.

b. Heaving or Settling of the Instrument or Rods.—This has often been cited as the cause of constant errors, but this explanation was usually offered in want of something better.

There is no doubt that disturbances of this kind take place occasionally when working over soft, springy, or frozen ground, but, when this is the case, the bubble never fails to show the danger, and the observer must then be on his guard.

The turning point pins, Fig. 4, when well driven, are scarcely susceptible to any heaving or settling of sufficient magnitude to be readable with an instrument, even at a very short range. When the instrument is affected it is hardly possible that the three legs of the tripod will move alike, and then the bubble will certainly indicate the disturbance long before it has attained a measurable magnitude.

This subject, therefore, disappears into insignificance, especially when the nature of the constant errors, frequently met, is more fully explained.

c. Air Vibrations and Refraction.—The former are caused by a complex refraction of the line of sight in passing through the air while it is undergoing a mixing process or agitation produced by the heat effect of the sun. Air vibrations become a maximum at or shortly after noon while the earth absorbs heat, and are most rapid and of greatest amplitude for clear, quiet days with high humidity. They cease when the sun has declined to the point where the earth no longer takes on heat and again appear in the coolness of the late afternoon, when the earth begins to radiate the heat absorbed during the day. These vibrations are diminished during the time when the sun is shut off by passing clouds and are entirely checked when the cloudiness is of sufficient duration.

Refraction, in the ordinary sense of the word, is a slowly changing deflection of the line of sight in passing obliquely through the concentric air strata surrounding the earth. This form of refraction changes most rapidly at sunrise and sunset, and is practically constant at noon. Since it changes slowly and with some degree of regularity, and is noticeable only on comparatively long sights (500 m. or more) little or no appreciable effect is produced thereby on level readings unless a considerable time elapses between taking back and fore sight readings late or early in the day. Constant refraction would introduce no errors, as it would affect back and fore sights equally.

The air vibrations can always be avoided by sufficiently reducing the length of sight, but when good readings cannot be taken at 25 m. the work should be suspended. Generally, the heat effect is such that good work is impossible long before this condition is reached. This will be shown in the following:

Some very interesting experiments* on this subject have been made by Leonard Sewall Smith, Assoc. M. Am. Soc. C. E.

d. Direction of Line, Time of Day and Season of Year.—The variety of effects produced on the results of levels by these conditions has been intimated but never explained. It is believed that these effects are all due to variations in the position of the sun and the intensity and direction of the sun's heat rays at different times during the day and year.

To prove this theory, the writer conducted a set of experiments which are given in part in Table No. 6. A great many readings, which are merely repetitions of those given, are omitted for the sake of brevity. These additional observations add nothing except to show conclusively that the changes found were substantiated by duplicate readings, and there could be no possible doubt as to the facts. Only the characteristic observations are here given. The experiments were made July 2d, 1899, near New Baltimore, Mich.

The instrument was set up on level ground and was carefully shaded with a large wagon umbrella. The rods were rigidly held in a vertical position and supported by the usual steel pins, driven flush

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* Bulletin of the University of Wisconsin, Vol. 1, No. 5, June, 1895, pp. 101–145.
See also results of observations made by C. H. Van Orden, M. Am. Soc. C. E., in *Transactions*, Am. Soc. C. E., Vol. xxxix, 1898, p. 387.

TABLE No. 6.—EXPERIMENTS TO SHOW

JULY 2D, 1899. BACK SIGHTS.

Point.	Rod No.	Thread readings.			Mean.	Thread distance.	Time.	Bearing to the sun.
		1	2	3				
		dcm.	dcm.	dcm.	dcm.	dcm.		
1.......	5	14.434 14.438 14.436	15.198 15.202 15.200	15.964 15.968 15.966	.... 15.201	.... 1.530	4.15 A. M.	Before sunrise.
1.......	5	14.540 14.544 14.542	15.290 15.304 15.297	16.056 16.060 16.058	.... 15.299	.... 1.516	10.00	S. 80° E.
1.......	5	14.536 14.536 14.536	15.294 15.296 15.295	16.054 16.052 16.053	.... 15.295	.... 1.517	10.45	S. 45° E.
1.......	5	14.532 14.538 14.535	15.294 15.298 15.296	16.056 16.056 16.056	.... 15.296	.... 1.521	11.00	S. 30° E.
1.......	5	14.538 14.536 14.537	15.296 15.296 15.296	16.056 16.056 16.056	.... 15.296	.... 1.519	12.00 M.	S.
1.......	5	14.536 14.534 14.535	15.296 15.296 15.296	16.054 16.056 16.055	.... 15.295	.... 1.520	1.30 P. M.	S. 50° W.
1.......	5	14.536 14.530 14.533	15.292 15.292 15.292	16.054 16.050 16.052	.... 15.292	.... 1.519	2.30	S. 70° W.
1.......	5	14.540 14.538 14.539	15.300 15.298 15.299	16.060 16.056 16.058	.... 15.299	.... 1.519	3.00	S. 75° W.
1......	5	14.540 14.536 14.538	15.298 15.296 15.297	16.058 16.058 16.058	.... 15.298	.... 1.520	3.35	S. 80° W.
1.......	5	14.538 14.540 14.539	15.296 15.298 15.297	16.056 16.058 16.057	.... 15.298	.... 1.518	4.15	W.
1.......	5	14.540 14 538 14.539	15.300 15.296 16.298	16.060 16.056 16.058	.... 15.298	.... 1.519	5.00	W.
1.......	5	14.540 14.536 14.538	15.298 15.292 15.295	16.058 16.052 16.055	.... 15.296	.... 1.517	5.35	W.

with the ground. The rods and instrument were on a straight line, bearing N. 33° E. Rod 5 was at Point 1, or the south end of the line, and Rod 1 was at Point 2, or the north end of the line; both were 30.4 m. from the instrument, thus eliminating all instrumental errors by equalizing the back and fore sights. The rods were graduated to 2 mm., thus reducing the errors of estimation to about ±0.05 mm. for the set of two readings of three threads each.

THE EFFECT OF HEAT ON LEVEL ERRORS.

FORE SIGHTS.

Point.	Rod No.	Thread readings.			Mean.	Thread distance.	Difference of elevation	Remarks. Weather.
		1	2	3				
		dcm.	dcm.	dcm.	dcm.	dcm.	mm.	
2.......	1	11.564	12.318	13.068	....	....	....	16.7° C. Reading good, air calm. Foggy, damp.
		11.566	12.322	13.072	....	....	....	
		11.565	12.320	13.070	12.322	1.505	+ 287.9	
2.......	1	11.660	12.426	13.178	....	....	....	Clear. 33.9° C. Reading fair; light warm wind.
		11.666	12.434	13.196	....	....	....	
		11.663	12.430	13.187	12.427	1.524	+ 287.3	
2.......	1	11.662	12.420	13.184	....	....	....	35°C. Bub. adj. clear. Light warm wind. Reading fair.
		11.660	12.420	13.180	....	....	....	
		11.661	12.420	13.182	12.421	1.521	+ 287.4	
2.......	1	11.660	12.424	13.186	....	....	....	35° C. Reading poor. Clear. Light warm wind.
		11.664	12.424	13.186	....	....	....	
		11.662	12.424	13.186	12.424	1.524	+ 287.2	
2.......	1	11.670	12.424	13.190	....	....	....	35° C. Reading poor. Air slightly unsteady. Light warm wind.
		11.662	12.424	13.186	....	....	....	
		11.666	12.424	13.188	12.426	1.522	+ 287.1	
2.......	1	11.660	12.420	13.180	....	....	....	33.3°C. Reading good. Sky overcast. Light warm wind.
		11.660	12.422	13.184	....	....	....	
		11.660	12.421	13.182	12.421	1.522	+ 287.4	
2.......	1	11.662	12.420	13.182	....	....	....	32.2°C. Reading good. Clear. Light W. wind.
		11.656	12.420	13.178	....	....	....	
		11.654	12.420	13.180	12.418	1.526	+ 287.4	
2.......	1	11.660	12.418	13.180	....	.. ..	....	30° C. Reading good. Cloudy; strong cool breeze from W.
		11.658	12.420	13.180	....	....	....	
		11.659	12.419	13.180	12.419	1.521	+ 288.0	
2.......	1	11.662	12.422	13.182	....	....	....	30° C. Reading fair. Partly cloudy, light W. wind.
		11.660	12.420	13.180	....	....	....	
		11.661	12.421	13.181	12.432	1.520	+ 287.7	
2.......	1	11.660	12.416	13.178	....	....	....	30.2° C. Reading fair. Clear; light W. wind.
		11.662	12.422	13.180	....	....	....	
		11.661	12.419	13.179	12.420	1.518	+ 287.8	
2.......	1	11.660	12.420	13.180	....	....	....	28.9° C. Reading fine. Cloudy; cool air; light W. wind; storm approaching.
		11.658	12.416	13.178	....	....	....	
		11.659	12.418	13.179	12.419	1.520	+ 287.9	
2.......	1	11.660	12.420	13.180	....	....	....	27.8°C. Reading good. Slight rain, cool and calm.
		11.654	12.412	13.174	....	....	....	
		11.657	12.416	13.177	12.417	1.520	+ 287.9	

The readings were taken by the usual manner of observing, viz.: With the telescope normal and the level tube direct, the back sight (three threads) was read first, and then, without in any way disturbing the instrument, not even to refocus, the fore sight was read, completing the first set. The level tube was then reversed, meanwhile inverting the telescope, and the second set of readings was taken, commencing with the fore sight. The means of the two sets for each thread and for the two sets are written on the third line of each observation. All readings were taken with the bubble in the center, and the instrument was not disturbed in any manner during the whole day, except after the first observation, which is taken with a different height of instrument, and the sights are not so nearly equal as for the subsequent observations. Otherwise the notes are self-explanatory.

Since all instrumental errors, except those due to collar inequality, are eliminated by the observations, the mean readings should always be the same unless influenced by atmospheric and temperature effects. Also, if back and fore sights are equally affected, the difference of elevation between the two points should remain constant. However, the difference of elevation did not remain constant, and back and fore sight readings changed, but the changes were unequal.

This phenomenon was not produced by refraction, because the sight (30.4 m.) was altogether too short to show refractive changes. It was not the result of air vibrations for the same reason, and in fact repeated readings by different observers never disagreed by more than 0.1 mm. No material vibrations could be observed which indicated sudden or rapid changes going on, except when passing clouds shut out the sun. The maximum producible change on the rods, due to the range of temperature gone through by the experiments, could not exceed 0.04 mm., which is too small to warrant consideration. The absolute temperature could not have been the cause, for the readings at 4.15 A. M. and 3 P. M., while they agree, were taken at widely different temperatures, and others taken at only slightly different temperatures near noon, show the widest departures.

The following explanation is given to account for this large error, amounting to 0.9 mm. in a distance of 60.8 m. during the hottest part of July 2d, 1899, and becoming zero at about 8 A. M. and 3 P. M. on that day: The afternoon limit was usually between 4 and 5 P. M., but the cloudiness brought on the normal conditions much earlier on the day in question; in fact the notes indicate that whenever the sun was completely shut off the readings came back to normal. It, therefore, follows that at certain times during the hottest portion of the day the sun affects instrument pointings differently for different directions of pointing, and that before and after this critical portion of the day such an effect does not exist even though the temperature remains high. Hence, the direction and intensity of the sun's rays seem to be the entire cause of the error.

It appears from the observations that the back-sight readings, pointing southward and toward the sun, do not show much variation, while the fore-sight readings show a maximum variation of 1 mm. This might be explained by the effect of the reflected heat rays from the ground being partly cut off by the observer while reading the fore sight and not while reading the back sight.

The heat effect from above remained about constant. This would tend to curve the eye end of the telescope downward on the fore sight and thus incline the line of sight upward, while the back sight would receive heat from above and below and remain practically unaffected.

For different ground and other umbrella covers, the effect may be very different or even reversed. Hence the importance of more experiments in this direction, and the necessity of confining level work to the early and late hours of the day during warm weather.

The foregoing experiments show that a direct line run shortly after sunrise might differ in result from a reverse line run between 10 and 11 A. M. by practically 0.9 mm. per 60 meters, or 15 mm. per kilometer, the error being entirely in the reverse line. Again, a direct line run between 10 and 11 A. M. might close well with a reverse line run between 1 and 3 P. M,, yet both be materially in error.

While errors from this source cannot be eliminated in any possible manner, their presence may be detected by always closing a stretch during the same half of the day. If, then, the closure is within the allowable limits, it is safe to assume that the temperature effect just described did not exist or was extremely small. When the closure is wide, due to this source of error, then the most erroneous line is the one run nearest to noon. An experimental line southward, on a clear warm day, between 2.30 and 4.15 P. M., without any umbrella, differed from the result obtained by duplicate lines on a cloudy day by 100.6 mm. The length of the line was about 1 km., and the one run without the umbrella was too high.

This coincides in sign with the foregoing experiments, though the closure is very large and might be attributed to a decimeter error had not a foot-rod been used on the line in question,

From this it is seen clearly that the umbrella is absolutely indispensable, and a large umbrella of close white duck lined with two thicknesses of heavy green or black cloth, leaving air spaces between the several coverings, is best suited to the work.

When high-grade work is necessary during the warm summer months, conditions permitting, it would be advisable to run the levels during the night. This will be found far more satisfactory, and failures to close will scarcely ever occur. Such a programme is feasible only when the line passes over good even roads and with proper equipment for illuminating the rods and the bubble.

The best months in the year for precise level operations in the Northern and Central States are April, May, September, October and November, and sometimes March and December. It is best not to work during June, July and August, though, with extraordinary exertions, good results may be obtained. No good work can be done during the cold winter months.

In closing, the following conclusion may be drawn respecting duplicate lines of levels:

1. Lines run simultaneously in the same or opposite directions may close well, yet both be in error, depending on the time of day during which they were run.

2. Lines run in the same or opposite directions during symmetrical parts of the day, with respect to noon, may close well and both be erroneous, depending on the heat conditions.

3. Lines run in the same or opposite directions at different times of the same half of the day may close wide, and the most erroneous line will be the one run nearest to noon.

Instrument Adjustments and Constants.

1. Introductory.

In taking up this subject it is necessary to mention in advance some of the controlling features of accurate level observations in general.

The instrument must be handled with great care, and should always be securely clamped while being carried. The observer should always carry the level tube and umbrella, leaving the umbrellaman to transport the instrument, thus enabling the observer to remain quiet and preserve a steady hand for manipulating the level. The instrument must always be shaded, and a cloudy day is very desirable when determining instrument constants. No work should be done during the heat of the day.

A base line, 100 m. long, should be accurately measured on even ground, marking the 0, 10, 20, 40, 50, 60, 80 and 100-m. points by oak stakes securely driven, with a spike in each on which to hold the rod.

The instrument should be planted firmly and must not be disturbed or shaken. Visitors should be kept at a safe distance.

The telescope should be sharply focused within the reading limits of the reticule, and the temperature of the instrument should not be affected by handling.

2. Instrument Adjustments.

Different instruments may require slightly different adjustments, but, in general, those necessary for an instrument of such a type as the Buff and Berger Precise Level No. 2768, Plate XXXIV, apply to nearly all high-grade instruments. These adjustments are as follows:

a. The Adjustment of the Small Tubular Levels.—For coarse setting of the instrument, this adjustment is conducted as for the plate levels of a transit, and would be the same for a watchglass level such as used on the Kern instrument, Fig. 1, Plate XXXV. The levels are brought to the center by means of the leveling screws and the instrument is then revolved 180° about its vertical axis. If the bubbles remain in the center they are in adjustment, otherwise adjust for half the error and repeat the process.

b. To Make the Horizontal Threads Horizontal.—These threads should be horizontal for both the normal and inverted positions of the telescope. Adjust the stop device until the mean horizontal thread gives the same reading on a rod when the previously leveled instrument is swung slightly in azimuth, so that the rod passes through the entire field of the telescope. This is done for the telescope normal and inverted, and should be repeated until no appreciable error remains.

c. To Make the Thread Adjustment.—Sight on a rod placed about 50 m. away. Read three threads with telescope normal and level tube direct, then invert telescope and read the three threads again, having the bubble in the center each time. The difference between the means for the two sets is the thread error, which is corrected by moving the reticule by one-half the amount of the error. The test is then repeated. This error may readily be reduced to 0.2 mm. in 50 m. and should not be allowed to exceed 1 mm. for the same distance.

After making this adjustment it is well to test the mounting of the objective lens, which is done by watching the image of an object while the telescope is being revolved. If the image and the reticule appear to move together in a circle, then the objective is eccentrically mounted. Another test is to read a rod with bubble in center, then unscrew the objective lens sufficient to move it through 180° and repeat the reading. Allowing for the play between the threads, the two readings should coincide.

d. To Make the Level Tube Parallel to the Telescope Axis.—This is done by two adjustments, the lateral and the vertical. The instrument is carefully leveled and clamped, the bubble is brought to the center, and then the level tube is tilted laterally and the bubble allowed to come to rest. If this position of rest is not in the center, then the proper end of the level tube must be adjusted laterally until the bubble remains in the center for all positions of tilt permissible between the forked lateral supports. This adjustment should be carefully made and be frequently tested, as errors due to such lack of adjustment cannot be corrected.

The vertical adjustment of the level tube is performed by clamping the instrument in a level position, bringing the bubble to the center, and then reversing the level tube on the telescope collars. If the bubble comes to rest in the center, after reversal, the level tube is in adjustment, otherwise adjust half the error on the vertical adjustment of the level tube and take up the other half on the leveling screws. Repeat the operation until the error does not exceed one second in pointing, or one 2-mm. division of a 2-second level. Strictly speaking, the level tube is made parallel to the elements of contact between the level tube and the telescope collars, while the telescope axis is determined by the relative sizes of the collars, which are generally unequal. This subject is taken up later.

e. The Parallax of the Level Tube Mirror.—This is removed by adjusting the inclination of the mirror to such an angle that the bubble is seen in the same position whether viewed in the mirror by the observer with his eye at the eyepiece of the telescope, or as seen directly by a second observer. This adjustment should be carefully made for the length of bubble to be used, and generally requires no further attention.

f. The Verticality of the Rods.—This must be tested three or four times daily by suspending a plumb-bob between points provided on the rods for this purpose. The rod is supported against a house or tree, away from the wind, and the rod level is centered when the plumb-bob shows the rod to be vertical.

3. Determination of Magnifying Power.

There are several methods of accomplishing this, and the two simplest will be here given. Both are based on the same principle.

a. First Method.—The rod is held at a convenient distance, L, from the instrument and the apparent size, T, of the image produced by a decimeter space (0.1 m.), is taken in a pair of dividers held at a certain distance l from the eye. This is accomplished with considerable accuracy by viewing the image with one eye and the dividers with the other. The apparent size of the image is then measured on a scale, and the distance from the eye to the dividers must be measured by an assistant, or, if the dividers are held opposite the objective, the length of the telescope may be used. Thus, for magnifying power $m = \frac{T\,L}{0.1\;l}$ the Buff and Berger Level No. 2768 gave, for $T = 0.105\ m$, $L = 20\ m$, and $l = 0.42\ m$, $m = \frac{0.105 \times 20}{0.42 \times 0.1} = 50$ diameters.

b. Second Method.—The following method is somewhat simpler, though not so well suited to telescopes of high magnifying power. The instrument is sighted on a rod set as close as the focusing slide will permit. The thread interval is then read through the telescope in the ordinary manner and also in its apparent size, as seen projected against the rod, by viewing the image through the telescope with one eye and the rod with the other. The ratio between the two intervals thus obtained is the magnifying power. Thus, for the same instrument placed 10 m. from the rod, the interval read through the telescope was 0.47 dcm. and the apparent interval projected on the rod was 23.50 dcm., hence $m = \frac{23.50}{0.47} = 50$ diameters.

4. Determination of One Division of the Level Tube.

A rod is held at some even distance from the instrument and the bubble is brought to rest near one end of the tube, but within limits of the graduation. The three threads are read, likewise both ends of the bubble. The bubble is then brought to rest near the other end of the tube and the readings repeated. The two sets furnish the observations for one determination. Five to ten determinations will give a very good mean value.

The graduations of the level tube are numbered from the center toward the ends, and the rod readings are expressed in decimeters, likewise the distance from the instrument to the rod. Calling E_1 and O_1 the eye end and object end readings, respectively, when the bubble was near the eye end of the telescope, and R_1 the corresponding rod reading; likewise E_2 and O_2 the bubble readings when the bubble was near the object end for which the rod reading R_2 was taken; also, calling l the distance from rod to instrument, and v the value, in seconds of arc, of one division of the level tube; then,

$$v = \frac{R_2 - R_1}{l\left(\frac{E_1 - O_1}{2} - \frac{E_2 - O_2}{2}\right)\sin 1''}$$

for a single determination, and,

$$v = \frac{\Sigma\,(R_2 - R_1)}{l\,\Sigma\left(\frac{E_1 - O_1}{2} - \frac{E_2 - O_2}{2}\right)\sin 1''}$$

for any number of determinations.

Table No. 7 gives an example in which five determinations were made for level tube Adolf Pessler, Buff and Berger Level No. 2768, with 2-mm. graduations.

The readings were taken on 10-mm. rod graduations.

5. Determination of the Distance Constants.

According to the principle of the stadia, previously cited in describing the parts of a telescope, the length of shot from the center of the instrument to the rod is $l = k\,i + c + f$, in which k is the stadia constant, f is the focal length of the objective and c is the distance from the center of the instrument to the optic center of the objective lens. Hence, if the length l is to be measured, the constants k, c and f must first be determined for the instrument used.

The constants c and f may be found by direct measurement, observing that the telescope should be focused on a distant object before measuring f, which is then the distance from the reticule (or capstan adjusting screws) to the center of the objective.

From the above equation it is seen that $k = \frac{1}{i}\,[l - (c + f)]$ from which k is determined by experiment.

TABLE No. 7.

Grossepoint, Mich., June 19th, 1899.
Temperature, 88° Fahr. 31.1° Cent.

POINT.	Rod No.	THREAD READINGS.			Mean.	Thread distance.	LEVEL.		$E-O$	v.
		1	2	3			E	O		
		dcm.	dcm.	dcm.	dcm.	dcm.	div.	div.	div.	sec.
		Telescope normal, level tube direct.								
a	1	15.034	16.264	17.500	16.266	2.466	21.8	8.8	+13.0	
		15.104	16.340	17.572	16.339	2.468	8.3	22.3	−14.0	
			$R_2 -$	$R_1 =$	+0.073	$\frac{E_1-O_1}{2} - \frac{E_2-O_2}{2} =$			+13.5	2.230
a	1	15.014	16.250	17.484	16.249	2.470	24.8	6.2	+18.6	
		15.100	16.338	17.568	16.335	2.468	8.9	22.1	−13.2	
			$R_2 -$	$R_1 =$	+0.086	$\frac{E_1-O_1}{2} - \frac{E_2-O_2}{2} =$			+15.9	2.228
a	1	15.050	16.290	17.524	16.288	2.474	18.5	12.8	+5.7	
		15.120	16.358	17.590	16.356	2.470	6.0	25.3	−19.3	
			$R_2 -$	$R_1 =$	+0.068	$\frac{E_1-O_1}{2} - \frac{E_2-O_2}{2} =$			+12.5	2.240
a	1	15.100	16.338	17.570	16.336	2.470	26.9	4.8	+22.1	
		15.200	16.436	17.668	16.435	2.468	8.9	22.8	−13.9	
			$R_2 -$	$R_1 =$	+0.099	$\frac{E_1-O_1}{2} - \frac{E_2-O_2}{2} =$			+18.0	2.267
a	1	15.116	16.350	17.584	16.350	2.468	24.7	7.0	+17.7	
		15.220	16.454	17.688	16.454	2.468	5.1	26.4	−21.3	
			$R_2 -$	$R_1 =$	+0.104	2.4686 $\frac{E_1-O_1}{2} - \frac{E_2-O_2}{2} =$			+19.5	2.198
		true dist. = 499.72 dcm.								
		$\Sigma(R_2 - R_1) = +0.430$ dcm.				$\Sigma\left(\frac{E_1-O_1}{2} - \frac{E_2-O_2}{2}\right) =$			+79.4	2.234 mean.

Hence $v = \frac{0.430}{499.72 \times 79.4 \times 0.000004858} = 2.234''$, or since $1'' = 0.004858$ mm. per meter, $v = 0.0108$ mm. per meter, which is sometimes a more convenient form.

The value as determined by Adolph Pessler, with the aid of a level-trier, was 1.97" (temperature not given). The agreement is as close as might be expected between a laboratory determination and one made in the open air at probably a much different temperature.

For the foregoing determination the probable error of the mean value 2.234" is ± 0.007".

To do this the instrument is set up on the measured base line, previously mentioned, at a distance $c + f$ behind the zero mark of the base, so that the measured lengths, counting from the zero of the base, are all $l - (c + f)$. If then a rod be set at some one of the base points and the two extreme threads are read, the thread interval thus obtained gives one value for k.

Generally five such sets of readings are taken for each of several points of the base, from which a mean value of k is found. Table No. 8 gives such a determination in detail.

TABLE No. 8.—DETERMINATION OF THE STADIA CONSTANT k FOR BUFF AND BERGER LEVEL No. 2768. CLAYTON, N. Y., MAY 5TH, 1899.

$l-(c+f)$	Rod No.	THREAD READINGS			Temp.	THREAD INTERVALS.			k	Remarks.
		1	2	3		Upper.	Lower.	Total.		
m.		dcm.	dcm.	dcm.	deg C.	dcm.	dcm.	dcm.	ratio.	
15	5	12.624	13.000	13.380	16.7	....	....	....	......	Tel. normal.
	......	12.610	12.990	13.360	....	....	....	....	......	
	......	12.600	12.980	13.350	....	....	....	....	......	
	... ..	12.652	13.026	13.402	....	....	....	....	......	
	......	12.650	13.020	13.400	....	....	....	....	......	
	m.	12.627	13.003	13.378	....	0.376	0.375	0.751	199.74	
15	5	12.650	13.024	13.402	....	....	....	....	......	Tel. inverted.
	......	12.624	13.000	13.380	....	....	....	....	......	
	......	12.600	12.978	13.350	....	....	....	....	......	
	......	12.650	13.022	13.400	....	....	....	....	......	
	......	12.580	12.950	13.324	....	....	....	....	......	
	m.	12.621	12.995	13.371	....	0.376	0.374	0.750	200.00	
50	5	11.400	12.650	13.900	....	....	....	....	......	Tel. normal.
	......	11.350	12.600	13.846	....	....	....	....	......	
	......	11.380	12.620	13.878	....	....	....	....	......	
	......	11.450	12.702	13.950	....	....	....	....	......	
	......	11.400	12.650	13.900	....	....	....	....	......	
	m.	11.396	12.644	13.895	....	1.248	1.251	2.499	200.08	
50	5	11.400	12.648	13.900	....	....	....	....	......	Tel. inverted.
	......	11.412	12.664	13.912	....	....	....	....	......	
	......	11.340	12.592	13.840	....	....	....	....	......	
	......	11.424	12.680	13.922	....	....	....	....	......	
	......	11.500	12.752	14.000	....	....	....	....	......	
	m.	11.415	12.667	13.915	....	1.248	1.252	2.500	200.00	
100	5	17.300	19.804	22.300	....	....	....	....	......	Tel. normal.
	......	17.220	19.724	22.222	....	....	....	....	......	
	......	17.400	19.902	22.400	....	....	....	....	......	
	......	17.304	19.806	22.304	....	....	....	....	.....	
	......	17.404	19.906	22.402	....	....	....	....	......	
	m.	17.326	19.828	22.326	....	2.502	2.498	5.000	200.00	
100	5	17.422	19.926	22.426	16.5	....	....	....	......	Tel. inverted.
	......	17.590	20.088	22.590	....	....	....	....	......	
	......	17.520	20.024	22.524	....	....	....	....	......	
	......	17.450	19.946	22.446	....	....	....	....	......	
	......	17.504	20.004	22.506	....	....	....	....	......	
	m.	17.497	19.999	22.498	....	2.499	2.502	5.001	199.96	

Mean..199.96

Note: The instrument was set $c+f=0.60$ m. behind the zero of the base. The smallest rod graduation was 1 cm.; magnifying power of telescope 50 diameters. Thread 1 is uppermost in the field of the telescope, whether the latter is normal or inverted, but the upper half-interval is always the same and becomes the lower half-interval for telescope inverted.

The value found is practically 200, or, for distances in meters and rod readings in decimeters, the constant becomes 20, and $c+f=$ 0.60 m.

When k is not an even hundred, the solution of the foregoing formula for distance becomes somewhat laborious, and a tabulation of values of $k\ i$, in meters, for assumed values of i, in decimeters, from 1 to 100, is very convenient for taking out any distances, even for a whole stretch. To obtain l for a single shot, the constant $c+f$ must be added to the tabulated value of $k\ i$, while for a stretch of n instrument settings the length becomes $L = k\ I + 2\ n\ (c+f)$, in which I is the sum of the thread intervals for all back and fore sights of the stretch.

6. Determination of the Error due to Collar Inequality.

The method adopted by the writer is designed to determine the residual inclination in the line of sight caused by inequality in the telescope collars, independent of the various other level tube and telescope errors, by a direct inductive method. The text-book method of determining collar inequality, by level tube and telescope reversals, has already been explained and found erroneous, because not all of the governing conditions are considered.

Observations are taken on the measured base previously mentioned, using the method of reading adopted for regular precise level work.

The instrument, which has been carefully adjusted, is set up at the 50-m. point of the base, and five or ten sets of sights are taken on rods held at the zero and 100-m. points, as follows: With telescope normal and level tube direct, the back sight is read on the rod held on the zero point of the base, the instrument is then swung on the rod at the 100-m. point and the fore-sight reading taken. The telescope is then inverted and the level tube is reversed and the readings are repeated, commencing with the fore sight. This constitutes one set of sights. All readings are taken with the bubble in the center.

The instrument is then set at some other point near one end of the base so that the back and the fore sights are very unequal. The 15-m. point was generally used. The same number of sets of sights is then taken as before on the rods at the zero and 100-m. points of the base.

It will be observed that this system of reading eliminates all errors of the level tube, the reticule, eyepiece movements, and mounting of the objective lens, and because the back and fore sights were exactly equal in the first series of sets, the remaining errors due to parallax and to inequality in the collars are also eliminated in these sets. However, the sets of the second series involve both these last-named errors for a 70-m. excess of fore sights. The parallax error should be eliminated by adjustment of the mirror, thus leaving the collar in-

TABLE No. 9.—DETERMINATION OF ERROR DUE TO

Clayton, N Y.,
MAY 5TH, 1899.

BACK SIGHTS.

Point.	Rod No.	Thread readings.			Mean.	Thread distance.	Temp.	Remarks.
		1	2	3				
		dcm.	dcm.	dcm.	dcm.	dcm.	deg. C.	
						Instrument at the 50-m. point of the		
0	1	11.570	12.800	14.036	....	....	....	Tel. N., Level D.
		11.558	12.798	14.026	....	....	....	Tel. I., Level R.
	M.	11.564	12.799	14.031	12.798	2.467	16.0	
0	1	11.976	13.206	14.442	....	....	....	
		11.970	13.200	14.430	....	....	....	Note:
	M.	11.973	13.203	14.436	13.204	2.463	....	Value of the level was 5″ per 2-mm. grad. The smallest graduation on the rods = 10 mm. The magnifying power of the telescope = 50 diameters. Length of bubble = 80 mm. Mirror adjusted for parallax. $c + f = 60$ m.
0	1	12.428	13.672	14.900	....	....	....	
		12.420	13.656	14.894	....	....	....	
	M.	12.424	13.664	14.897	13.662	2.473	....	
0	1	12.276	13.506	14.746	....	....	....	
		12.270	13.500	14.738	....	....	....	
	M.	12.273	13.503	14.742	13.506	2.469	....	
0	1	12.258	13.494	14.728	....	....	....	
		12.252	13.492	14.722	....	....	....	
	M.	12.255	13.493	14.725	13.491	2.470	15.8	
				Means	13.3322	2.4684		
						Instrument at the 15 m. point of the		
0	1	13.338	13.698	14.058	....	....	15.8	
		13.340	13.698	14.060	....	....	....	
	M.	13.339	13.698	14.059	13.699	0.720	....	
0	1	13.350	13.708	14.064	....	....	....	
		13.348	13.704	14.064	....	....	....	
	M.	13.349	13.706	14.064	13.706	0.715	....	
0	1	13.364	13.724	14.086	....	....	....	
		13.362	13.724	14.082	....	....	....	
	M.	13.363	13.724	14.084	13.724	0.721	....	
0	1	12.776	13.140	13.496	....	....	....	
		12.774	13.134	13.494	....	....	....	
	M.	12.775	13.137	13.495	13.136	0.720	....	
0	1	12.806	13.164	13.524	....	....	15.7	
		12.800	13.156	13.516	....	....	....	
	M.	12.803	13.160	13.520	13.161	0.717	....	
				Means	13.4852	0.7186		

equality as the only remaining source of error in the second series. Hence, the residual inclination is found by comparing the differences of elevation between the zero and 100-m. points as found by the two series of observations.

Temperature and atmospheric influences must be carefully avoided in these observations by choosing a proper time of day, or cloudy weather.

COLLAR INEQUALITY, BUFF AND BERGER LEVEL, NO. 2768.

FORE SIGHTS.

Point.	Rod No.	Thread readings.			Mean.	Thread distance.	Diff. of elev.	Remarks.
		1	2	3				
		dcm.	dcm.	dcm.	dcm.	dcm.	mm.	
100-m. base line, Clayton, N. Y.								
100	5	18.714	19.960	21.196	....	....	....	Tel. N., Level D.
		18.710	19.950	21.190	....	....	....	Tel. I., Level R.
	M.	18.712	19.955	21.193	19.953	2.481	—715.5	
100	5	19.122	20.366	21.600	....	....	....	
		19.120	20.360	21.600	....	....	....	
	M.	19.121	20.363	21.600	20.361	2.479	—715.7	
100	5	19.588	20.820	22.052	....	....	....	
		19.580	20.810	22.048	....	....	....	
	M.	19.584	20.815	22.050	20.816	2.466	—715.4	B. S. = 49.968 m. F. S. = 50.100 m.
100	5	19.432	20.670	21.900	....	....	....	Ex. F. S. + 0.132 m.
		19.420	20.660	21.898	....	....	....	
	M.	19.426	20.665	21.899	20.663	2.473	—715.7	
100	5	19.412	20.650	21.888	....	....	....	
		19.410	20.648	21.886	....	....	....	
	M.	19.411	20.649	21.887	20.649	2.476	—715.8	
				Means	20.4884	2.4750	—715.62	
100-m. base line, Clayton, N. Y.								
100	5	18.786	20.898	23.002	....	....	....	
		18.796	20.898	23.010	....	....	....	
	M.	18.791	20.898	23.006	20.898	4.215	—719.9	F. S. = 85.004 m. B. S. = 14 972 m.
100	5	18.800	20.906	23.010	....	....	....	Ex.F. S. + 70.032 m·
		18.800	20.902	23.010	....	....	....	
	M.	18.800	20.904	23.010	20.905	4.210	—719.9	Residual Excess F. S. = + 69.90 m.
100	5	18.804	20.914	23.024	....	....	....	
		18.810	20.920	23.036	....	....	....	
	M.	18.807	20.917	23.030	20.918	4.223	—719.4	True D.= —715.62mm. Err. D.= —719.98mm.
100	5	18.230	20.350	22.460	....	....	....	Resid. = + 4.36mm.
		18.220	20.328	22.446	....	....	....	for 69.9m. Excess F.S.
	M.	18.225	20.339	22.453	20.339	4.228	—720.3	
100	5	18.268	20.380	22.490	....	....	....	or = + 0.0624 mm. per meter Excess of
		18.236	20.350	22.464	....	....	....	F. S.
	M.	18.252	20.365	22.477	20.365	4.225	—720.4	
				Means	20.6850	4.2202	—719.98	

When the horizontal distance between the cradle supports of the telescope differs from the distance between the contact points of the collars with the level tube, then the only wear on the collars which affects the above residual inclination is that which takes place on the collars under the level tube. This wear is very slow and may be almost entirely prevented by applying the precaution of lifting off the level tube whenever the telescope is being reversed and when the instrument is being carried.

Past practice has been to construct the cradle and level tube with such dimensions as to bring the four contact points on each collar exactly in a plane. The wear resulting from the cradle supports will then affect the level tube bearings and the whole matter of collar inequality reaches a chaotic stage beyond all possibility of solution. Hence, this condition should be carefully avoided, and it might be suggested that a pair of collars be provided for the cradle supports independent of those for the level tube.

An example of a complete determination of the residual error due to collar inequality is given in Table No. 9. The result found is + 0.0624 mm. per meter excess of fore sights, which corresponds closely with the value + 0.0678 previously found by the old method with corrections applied. The rule for applying this error is therefore: On direct lines, the difference of elevation between two successive bench-marks is algebraically increased for a positive excess of fore sights, and on reverse lines the difference of elevation is algebraically increased for a negative excess of fore sights, provided, that the difference of elevation is given the same sign as for the direct line.

7. Eyepiece Movements.

When the eyepiece is afflicted with irregular movements for different focal distances, the thread adjustment becomes very unreliable, and, in fact, an instrument having such a defect is not suitable for accurate work.

The most dangerous error is produced by lateral looseness of the eyepiece slide, which causes the eyepiece to drop slightly after each inversion of the telescope, and thus vitiates all readings. Regular linear motion is necessary, even though the direction is inclined to the axis of the telescope. Such regular inclination is entirely eliminated by readings in the normal and inverted positions of the telescope, while the irregular looseness affects each sight and each position differently. Hence the importance of proper design and careful construction of this detail of the telescope, to which attention has already been invited.

To determine the presence and character of these eyepiece movements, the following tests should be made:

First, perform several inversions of the telescope, each time reading a rod placed 60 to 70 m. from the instrument. If these readings show no changes or marked variations in the thread error, then there is no lateral looseness of the eyepiece slide. However, it frequently happens that such looseness develops as a result of wear, or when working during extremely warm weather. It is well to have the eyepiece move somewhat hard, and a thick lubricant, such as tallow, is preferable in warm weather, while a more fluid oil may be used in cold weather.

Second, to determine the obliquity of motion of the eyepiece slide, the instrument should be set up 5 or 10 m. behind the zero mark of the measured base line and readings taken on such points, the elevations of which have been determined previously by shots of equal back and fore sights. Such a set of readings, which may be repeated several times for level tube direct and reversed, but without inverting the telescope, will give a profile of the line of sight, which should be a straight line. The inclination of this line of sight for the different points sighted should, of course, be constant, and by comparing this mean inclination with the error due to collar inequality, the resultant of the two is the inclination due to obliquity of eyepiece motion.

TABLE No. 10.—DETERMINATION OF OBLIQUITY OF EYEPIECE MOTION.

POINT.		Instrument set at point of base.	LENGTH OF		DIFFERENCE OF ELEVATION.		Error.	Excess of F. S.	Obliquity of line of sight.
To.	From.		B. S.	F. S.	True, for equal sights.	Erroneous for unequal sights.			
		m.	m.	m.	mm.	mm.	mm.	m.	mm. per meter.
20	0	60	60	40	+ 288.1	+ 289.6	−1.5	− 20	−0.0750
40	0	10	10	30	+ 501.6	+ 500.4	+1.2	+20	+0.0600
60	0	20	20	40	+ 737.4	+ 736.3	+1.1	+20	+0.0550
60	0	10	10	50	+ 737.4	+ 735.0	+2.4	+40	+0.0600
80	0	20	20	60	+ 897.9	+ 885.6	+2.3	+40	+0.0575
40	0	60	60	20	+ 501.6	+ 504.4	−2.8	−40	−0.0700
80	0	60	60	20	+ 897.9	+ 900.5	−2.6	−40	−0.0640
80	0	10	10	70	+ 897.9	+ 894.6	+3.3	+60	+0.0550
100	0	20	20	80	+1115.5	+1111.7	+3.8	+60	+0.0633
100	0	10	10	90	+1115.5	+1110.4	+5.1	+80	+0.0638

Mean = 0.0625.

Table No. 10 gives the results of a set of observations, for which each value is the mean of two sets of readings of three threads, each for level direct and level reversed. The error of estimation is probably large, because the observer (the writer) had not yet attained the necessary skill in estimating on 10-mm. rod graduations.

The instrument, Buff and Berger Level, No. 2768, was here placed at different points of the base line, but it would be better to follow the plan above outlined. The level tube had a curvature of 5″ per 2 millimeters, the smallest rod graduation was 10 mm., and the magnifying power of the telescope was 50 diameters. The ratio of the telemeter threads was 1:100, which is partly the fault of poor estimation on the extreme threads.

The obliquity of the line of sight found for excess of fore sights varying from 20 to 80 m. is practically constant, and hence the eyepiece moves in a straight line.

8. Determination of A of Rods.

This may be done by direct measurement, with a finely divided steel scale, or it may be accomplished with the aid of the leveling instrument.

The latter method consists of repeated readings taken on the rod held on a specially prepared spike head and then a second set of readings taken on a steel scale held on the same mark. The mean difference of the two sets of readings is the A of the rod.

Field Methods of Precise Leveling.

1. Organization and Subsistence of the Field Party.

a. Organization.—A field party, while it may be differently constituted to comply with conditions and circumstances peculiar to certain localities, is generally composed of an observer, who is chief of the party; a recorder, two rodmen and an umbrellaman. Sometimes an axeman is required when lines must be cleared of brush. A cook and camp outfit may be necessary when the party cannot subsist on the farming community.

A proper make-up of energetic, active, well-educated and practical men is the prime necessity when high-grade work is expected. The very best are none too good for precise leveling, and it is economy to employ only efficient men at high compensation, even for the better grades of railroad levels. This applies equally to the instrumental outfit with which a party is equipped.

On all astronomical and precise geodetic work the high degree of accuracy is attained by the most delicate instruments handled in a most skillful manner to obtain a large number of observations of each unknown quantity, from which the best mean values may be deduced.

According to most recent standards of precise leveling the accumulated error of say 9 000 individual rod readings, covering 400 klm. of levels, must not exceed 40 mm. and often falls below 10 mm. This must be accomplished in the open air, over any ground, and at nearly all seasons of the year. A certain daily rate of progress is expected, and the atmospheric conditions are frequently prohibitive of good work, thus forbidding the repetition of observations and the rejection of work which, though not perfect, must be accepted because it falls within certain arbitrary limits of requirement. There is no opportunity to select a best value or a mean of many observations. There is but one result and that must be correct within certain specified limits.

From this statement of the facts it becomes apparent that the ability and skill required of a precise levelman is of a very high order, somewhat at variance with the commonly accepted idea.

The observer and chief of a precise level party must be a specialist, possessing a thorough scientific training and having a faculty for careful and patient research united with a natural adaptation to artistic manipulations. He must always lead and provide for the welfare and comfort of his party, frequently to the extent of supplying medical aid. He must often be satisfied with a meager compensation and with little recognition for the quality of his services, because such service is rarely appreciated except by one who has been "through the mill" himself.

The recorder should be a college graduate with several years' practical experience, especially in the computing department of geodetic and survey work. He must be very quick and correct in recording and reducing observations, and must keep clean and legible notes. Much of the success of a party depends on the ability of the recorder to fill his position well.

The rodmen should be college graduates, as besides their regular duties of rodding, they must be able to check the field note reduction and computation made by the recorder. Without such assistance the labor devolving on the recorder and observer would be excessive, and the progress of the work would be retarded. The duties of the rodmen are exactly the same, and there should be no distinction, such as head and rear rodman.

There are no special qualifications attaching to the umbrellaman or possible axeman, except that the former must carry the instrument and must be cautious and trustworthy.

The chief of party should be allowed to appoint his own assistants, and he alone is then responsible for the quality and quantity of work performed. The several members of a party should be congenial, and pull together. The general principles, as well as the details of the work, should be familiar to all, and ample opportunity should be given for the free discussion of any doubtful matters which may arise.

b. Subsistence.—The peculiarities of leveling over long stretches of country necessarily bring about conditions which are radically different from other field work, and a few remarks on this subject may be in order here.

The engineer has often been compared with the tramp, which is more or less justifiable on some kinds of work; but when leveling is the subject under consideration, the slight distinctions, usually claimed in favor of the engineer, vanish into insignificance.

Owing to the rapid progress of a leveling party, it is necessary to move headquarters about every second or third day, and this prevents the use of a regular camping outfit, unless it be in the form of a gypsy caravan with team and wagon. This is generally more expensive than subsisting on the farming community, and is, therefore, not resorted to, except when passing through unsettled country.

Boarding with the farmers, however, is not always a pleasant existence, as those who have experience will testify. Every farmer wishes to profit by the misery of the party, and the usual result is that hotel rates are charged and tramp accommodations are offered. There are exceptions to this rule, but they are very rare and enjoy a long life in the memory of the levelman.

The personal baggage must be confined to a minimum, as there are times when each man must pack his own belongings and work as he goes. At other times a horse and buggy may be secured for this service.

Working hours are generally from sunrise until atmospheric interference prevents further progress, and again in the afternoon when work becomes possible until sunset. This makes the busiest time for the levelman at the usual breakfast and supper hours, which adds greatly to the discomfiture of both parties concerned.

The foregoing will suffice to enable the reader to draw his own conclusions regarding the pleasantries of the levelman's occupation.

2. Systems of Leveling.

The value of a single line of levels has often been over-estimated, assuming that careful, conscientious work would yield correct results. It is never known with absolute certainty, however, when work is correct unless at least two results are obtained, and even then cases are on record where both results were erroneous, yet agreeing fairly well with each other.

Several systems of duplicate leveling have been used with the distinct purpose to check work and at the same time to eliminate injurious atmospheric influences; also to detect heaving or settling of instruments and other sources of error. The methods commonly used were to run duplicate simultaneous lines, using one instrument and two sets of turning points, or two instruments and one set of turning points; to run duplicate simultaneous lines in opposite directions using two complete party outfits; to run duplicate lines in opposite directions by the same party, dividing the work variously between forenoons and afternoons. The method generally prevailing is to run one way in the forenoon and to duplicate the work in the opposite direction in the afternoon.

The experiments conducted by the writer, however (see Table No. 6), to show the effect of time of day and direction of line on the closure of level lines, answer this question very conclusively. Accordingly, there appears to be but one method of detecting the principal error due to temperature or radiation and that is to run duplicate lines in opposite directions by a single party, closing each stretch in the same half of the day. This, however, is merely a means of detecting the presence of errors from this source; such errors may be eliminated only by dividing the work equally between the two halves of the day for the entire line of levels.

This view is quite different from that ordinarily held by most authorities, but the conclusion above reached supersedes all theoretical reasoning, being, as it is, the result of actual observation and experiment.

On some recent Government work, a system of single lines has been adopted with the expectation of checking or closing the work by leveling in large polygonal lines forming a net. If such work be carried on in a continuously forward direction, the errors are very apt to be cumulative. If work be run direct and reverse on alternate days, the error will be materially reduced, but such a level line will be unsatisfactory and may embrace many serious local undulations and still close well on an entire polygon.

Hence, if high-grade work is required, it is absolutely necessary to run forward and back over each stretch, and, according to the writer's experience, each stretch should be closed in the same half of the day, choosing the length of the stretch to make this requirement possible.

3. Instrument Adjustments and Constants.

The manner of adjusting a level and determining its constants has already been given in full detail, and hence only a few remarks are necessary here.

When a party enters the field to commence leveling operations, the first thing is to measure a base line and mark the ends and intermediate points on bed-rock or on very solid stakes with large spikes for turning points. The instrument constants should then be carefully determined and a permanent record kept of all work done. The same observations should be repeated at the completion of the work, or at the close of the field season, if possible on the same base line.

The adjustments of the level should be tested every day before doing any leveling, and, if found excessive, the instrument must be carefully adjusted. As will be seen presently, the combined error of the cross-threads and level tube is measured by each set of observations, and, whenever this becomes excessive (exceeds 1 mm. in 50 m.), it is well to readjust the cross-threads and level tube. The lateral adjustment of the level tube and the plate levels do not require much attention, though the eyepiece movements should be constantly watched, as in extreme temperatures, irregularities often occur which would prove serious if not detected at the time.

When working with a very delicate level, great care should be exercised not to expose the instrument to sudden changes of extreme temperatures, as is very apt to occur in cold weather. The level should be maintained as nearly as possible at the atmospheric temperature, and should not be left standing in the sun or be placed in a warm room after being used in the cold.

Attention should be called to the fact that it is useless to attempt the adjustment of an instrument before it has stood long enough to take on an even temperature in the air where it is to be used. This may require 15 minutes or more after being removed from the case, and can be best determined by observing the constancy in the length of the bubble, which is a determining factor. A single reversal of the level tube is not considered sufficient to decide whether or not the level tube requires adjustment, but at least two, and generally three or four, are necessary to determine the real state of affairs. Hasty action will often cause much useless labor and delay. A level which was in adjustment when placed in the case will scarcely ever be so when again set on the tripod, but in a few minutes it frequently returns to perfect adjustment.

The rods should be tested regularly, morning, noon and evening, and, when not plumb, the rod levels should be adjusted.

It is not necessary, according to the method of observing advocated in the following, to measure and record errors of adjustment, as these errors are not sufficiently constant to justify their use in applying corrections.

4. Atmospheric Conditions Permitting Acceptable Work.

The opinions regarding this important factor are so varied that, to the inexperienced, it may seem impossible to follow any definite rule.

The majority of writers take the stand that work may be profitably carried on when the air is sufficiently quiet to enable the observer to obtain a good, steady image, when the rod is placed at about 30 m. from the instrument, independent of the time of day. This is entirely inadmissible in warm weather, as is clearly shown by the experiments given in Table No. 6.

A steady image is, however, only one of the many governing conditions for obtaining good work. It may be accepted as satisfactory evidence of normal conditions when the sun is completely hidden by dense clouds so that not merely the instrument, but the entire distance sighted over is in the shade.

On clear or partially cloudy days, great care and good judgment are required to obtain acceptable readings during midday hours, which in the warm summer months may comprise from 8 A. M. to 5 P. M., leaving only the early morning and late evening hours for work. In the cooler weather of spring and fall, leveling may be done at nearly all hours, though excessive dampness of the ground, combined with warm air, may frequently cause trouble.

The following method of observing is intended to furnish the means of detecting any abnormal atmospheric conditions or rapid changes, and the observer, if he is very careful, will soon learn to judge the reliability of his readings by the behavior of the bubble and the coincidence of his pairs of observations.

However, the error shown to exist in very warm weather (see Table No. 6) cannot be detected, except by the closure of a line, and the best and most careful work may be done under seemingly good conditions without yielding satisfactory results.

To test the atmospheric conditions, the following method may prove serviceable when working in very warm weather. At a convenient place near each camp, drive three stakes in approximate direction of the level line and about 50 m. apart (set by the level). Large spikes should be driven in the first and third stakes. The instrument is set up over the center stake, and the difference of elevation between the first and last stakes is carefully determined very early or very late in the day or during cloudy weather. Whenever the atmospheric condition is uncertain it may be tested by setting the instrument over the middle stake and taking a set of readings on the first and third stakes. If the resulting difference of elevation does not check the one previously found under known conditions within the allowable error of estimation, then no acceptable work can be executed.

Working during the warm summer months, June, July and August, has many disadvantages, and the recommendation previously made, respecting the advisability of night leveling will be well worth consideration if within the limits of possibility.

5. Method of Observing.

The method of observing, advocated by the writer, is such as to eliminate all instrumental errors in the observations themselves, and obviate, as far as possible, all mathematical manipulations in the form of corrections. It is held that careful observations, taken only under suitable atmospheric conditions, will lead to better results than can ever be expected by applying more or less speculative corrections to work of less exact execution.

The instrument should always be completely shaded from the direct rays of the sun, and should be protected from rain and annoying winds. This can, with rare exceptions, be accomplished with a large instrument umbrella, as previously described. So-called wind protectors are not considered practical when using a good firm tripod, such as supplied with Buff and Berger Level No. 2768, though they are valuable when using less rigid tripods. One of the best forms of protectors was designed by E. E. Haskell, M. Am. Soc. C. E., and consists of three 10-ft. poles forming a tripod, which latter is covered with canvas to form a portable tent. Openings for taking readings are provided.

All rod readings are taken on rods, held perfectly plumb by means of spirit levels, and three threads are read for each sight. The bubble is always in the center when readings are taken, and the observer sees the rod image with one eye simultaneously with the bubble image in the mirror with the other eye.

The rods are placed equidistant from the instrument by the rodmen counting their paces. The rodmen become alternately head and rear rodman, thus having exactly the same duties and responsibility.

One rod is held on a starting bench-mark and the other on the first turning point; the readings are taken and the instrument and rear rod are then carried forward to new positions. The rear rodman counts his paces from the first turning point to the new instrument position and then proceeds ahead, repeating his count to the second turning point. This process is continued until a new bench-mark is reached. The instrumentman thus fixes the length of shot he wishes to take, and both rods are always in position when readings are taken.

The readings, constituting one pair of back and fore sights, are taken as follows: With the telescope normal and the level tube direct, the first sight of the back sight is taken with the bubble in the center. Then, without disturbing the telescope, not even touching the focusing screw or level tube, the instrument is quickly swung on to the front rod and the first sight taken on the fore sight as soon as the bubble can be centered by the micrometer screw. Should the lengths of the shots be materially unequal, the front rod is set correctly and the sights are repeated. The level tube is then removed and the telescope is inverted, carefully replacing the level tube in a reversed position. The second sight of the fore sight is then taken with the bubble in the center; the instrument is quickly swung on to the rear rod and the second sight of the back sight is taken.

Before taking up the instrument, the recorder inspects the two sets of readings to ascertain any possible inconsistencies, and, if any are discovered, the readings are repeated; otherwise, the instrument is carried forward, and the recorder takes out the mean readings and thread distances while the instrument is being reset.

In closing on a bench-mark, the instrument is so placed, on the last pair of sights, as to make the sum of the thread distances of the back sights equal to the sum of the thread distances of the fore sights for the entire stretch between bench-marks. The difference of elevation and total length of stretch is then figured and the stretch run in the opposite direction during the same half of the day. The closure of the loop thus run must be less than the specified limit given in the following.

By this method of observing, the errors of pointing and of estimation are materially reduced and become almost insignificant, as compared with those incident to other methods, while the errors of the telescope and level tube are eliminated, to all intent and purpose. The only correction to be applied to the work is for rod length and temperature as above described.

Should the sums of sights not be entirely equalized, then the "residual correction" due to collar inequality, etc., must be applied for the resulting excess of fore sights. Further than this, no corrections of any kind are necessary or applicable to the field notes.

When a bench-mark is so placed that the level rod cannot be held directly on the mark as on a turning point, then a steel tape is most advantageously used at short range. Such a tape has been described in connection with level rods, and the value "A" for the rods used must be subtracted from all tape readings when the tape is stretched upward from the mark.

On direct lines, the back sights are considered positive and the fore sights are negative, while on reverse lines these signs are advisedly reversed, thus giving the same sign to the difference of elevation whether determined from a direct or reverse line.

A line is considered "direct" when going from the initial or starting point toward the terminal point. The opposite direction is considered "reverse."

6. System of Notes.

The method of observing was treated somewhat briefly, with the expectation of illustrating the details of the method here advocated by a complete example of notes, thus presenting the subject in a more understandable manner.

The following books constitute the records of a precise level party: A notebook of bench-mark descriptions; as many notebooks as may be necessary for level notes; and a summary-book containing a compilation of final results and computation of elevations. In addition to these notes the level line and all fairly permanent bench-marks should be platted on some large-scale map of the route, whenever such a map is obtainable.

The level fieldbooks should be about 5 x 7½ ins., with printed headings, vertical column ruling, and horizontal lines ruled $\frac{3}{16}$ in. apart. The summary-book should be about 9 x 12 ins., of paper ruled crosswise with about seven squares to the inch. The headings can be printed, or stamped with a large rubber stamp, and the columns ruled by hand.

Each fieldbook should contain on the front page a brief statement of programme of observing, definitions of instrument positions, names of observer and recorder, instrument and rods used, units of measure adopted, etc. The notes should then follow in chronological order in strict accordance with the system adopted. The last double page of each book should contain a summary of results with page index of work recorded in such book.

The summary-book should contain a similar introduction, with definitions of terms used therein, authority and elevation of starting bench-mark and a brief history of the work.

It is scarcely necessary to give an example of bench-mark descriptions, though it must be emphasized that too much attention cannot be given to the accurate and complete description of every permanent bench, as appears from the purpose for which such a description should serve. A very good test of the adequacy of such descriptions is for the observer to place the bench and draft the first description. The recorder should then find the bench with the aid of this description, and, if the latter is found deficient, it must be improved.

A complete example of a field level-book is given in the following, and applies to Buff and Berger Level, No. 2768 (see Plate XXXIV).

Designation of Instrument Positions.

"1. The telescope points direct when its eye end is over the micrometer bearing of the wye-cradle. This position is always maintained when leveling.

"2. The telescope is normal when the focusing screw at the eye end is on the upper right-hand side as seen from the position of the observer.

"3. The level tube is in its direct position when the end marked 'chamber' is at the eye end of the telescope.

Programme of Readings.

"1. For each position of the telescope, the three threads are read consecutively from the upper thread down, and the readings are recorded in this order as 1, 2 and 3, whether the telescope is normal or inverted.

"2. Each shot is the mean of six thread readings taken for the two following positions of telescope and level tube: 1. Telescope normal, level direct; 2. Telescope inverted and level reversed. Thus each shot or pair of sights eliminates errors in the adjustment of the cross-threads and the level tube.

"3. The thread distance corresponding to the mean value of the two instrument pointings, or sights, is obtained by subtracting the mean for thread 1 from the mean for thread 3.

"4. Thread distance, in decimeters, is converted into true distance, in meters, by the formula

$$L = kI + 2n\,(c + f),$$

in which $I = \Sigma_0^n\, i =$ total thread distance, in decimeters, for any stretch of n instrument settings. The stadia constant, k, is 20 for thread ratio 1:200. The telescope constant $c + f = 0.6$ m.

"5. All rod readings are read and recorded in decimeters.

"6. No bubble readings are recorded, because the bubble is always in the center when rod readings are taken. However, when the bubble is read, for experimental purposes, the readings termed 'eye end' (E) are taken for the eye end of the telescope whether the level tube is direct or reversed. For regular level work, the length of the bubble is maintained at 40 divisions = 8 cm.

"7. The allowable limit of error for the closure of each stretch is $2\sqrt{L}$, in millimeters, in which L is the length of the stretch, in kilometers.

"8. Buff and Berger Precise Level No. 2768, and Lake Survey rods 1 and 5 were used. For summary of results see p. — of this book.

"D. M., Observer; M. B., Recorder; A. E. and A. H., Rodmen."

Instrument Constants.

The instrument constants were determined whenever the instrument underwent any changes or alterations, and at the beginning and end of each field season. The values used in this book are given in Table No. 11.

TABLE No. 11.

Designation of constants.	Values.
Magnifying power of telescope, in diameters	50
Focal length of objective, in millimeters	402
Diameter of objective, in millimeters	38
Ratio of telemeter threads	1:200
Curvature of level tube, in seconds per 2-mm. divisions	2.23
Residual error, in millimeters per meter excess of F. S. for + difference of elevation	+ 0.0630
Weight of instrument, in kilogrammes	5.3
Weight of tripod, in kilogrammes	7.6
Smallest graduation on rods, in millimeters	10
A of rods 1 and 5, in decimeters	0.486

Level Notes.

Tables Nos. 12 and 13 are the complete field notes of a stretch of levels, direct (*D*) and reverse (*R*). During the progress of the work the recorder carries (in lead pencil) a continuous summation of thread distances, to prevent any excessive inequality in sums of sights (say larger than 2 m.). On the last setting the instrument is so placed that the final sums should balance. Only the final sums are retained in the notes, the others are again erased when the notebooks are checked, which is done each night by the rodmen. All notes as given in the sample, except final sums, are recorded in ink, thus preventing any erasures or obliterations.

An example of a river crossing (Tables Nos. 14 and 15) is inserted to indicate the special features of such a problem, which often presents itself and which frequently involves numerous difficulties. The notes also show in a remarkably striking manner the correctness of the new theory of collar inequality developed herein.

(*Left-hand page.*)

TABLE No 12.—Example

Direct Line T. B. M.

July 5th, 1889. Back Sights.

Point.	Rod No.	Thread readings.			Mean.	Thread distance.	Temp.	Remarks.
		1	2	3				
		dcm.	dcm.	dcm.	dcm.	dcm.	deg, C.	
T. B. M. 128.	1	24.174	26.006	27.838	....	....	23.9	3 P. M.
		24.176	26.008	27.840	....	....	....	Cloudy, fresh
		24.175	26.007	27.839	26.007	3.664	....	wind, reading good.
T. P. 1.....	5	20.336	22.050	23.764	....	....	....	Puffy, cool wind.
		20.336	22.052	23.766	....	....	....	
		20.336	22.051	23.765	22.051	3.429	....	
2	1	14.606	16.290	17.970	....	....	....	Cloudy.
		14.602	16.284	17.964	....	....	....	
		14.604	10.287	17.967	16.286	3.363	....	
3	5	17.648	19.244	20.842	....	....	....	Sun shining;
		17.652	19.248	20.844	....	....	....	brisk puffy
		17.650	19 246	20.843	19.246	3.193	....	wind.
4	1	8.524	10.104	11.688	....	....	....	Cloudy.
		8.512	10.096	11.678	....	....	....	
		8.518	10.100	11.683	10.100	3.165	....	
5	5	21.024	22.646	24.270	....	....	....	Cloudy; wind
		21.024	22.646	24.268	....	....	....	abating.
		21.024	32.646	24.269	22.646	3.245	....	
6	1	19.260	20.922	22.580	....	....	....	B. S. + 156.357 F. S. — 112.384
		19.258	20.916	22.576	....	....	....	D = + 43.973
		19.259	20.919	22.578	20.919	3.319	....	Res. Cor. 0.000
7	5	17.520	19.104	20.690	....	....	....	Light wind.
		17.516	19.098	20.684	....	....	....	
		17.518	19.101	20.687	19.102	3.169	....	
					156.357	26.547		

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* Taken from precise level line along

OF PRECISE LEVEL NOTES.* (*Right-hand page.*)

128-T. B. M. 129.

FORE SIGHTS.

Point.	Rod No.	Thread readings.			Mean.	Thread distance.	Temp.	Remarks.
		1	2	3				
		dcm.	dcm.	dcm.	dcm.	dcm.	deg. C.	
T. P. 1......	5	14.262	16.094	17.922	....	....	....	
		14.264	16.096	17.924	....	....	....	
		14.263	16.095	17.923	16.094	3.660	....	
2	1	8.924	10.684	12.450	....	....	....	
		8.924	10.686	12.450	....	....	....	
		8.924	10.685	12.450	10.686	3.526	....	
3	5	16.398	18.002	19.600	....	....	....	Sun out on first
		16.390	17.994	19.598	....	....	....	reading of F. S.
		16.394	17.998	19.599	17.997	3.205	....	
4	1	13.934	15.558	17.186	....	....	....	
		13.938	15.562	17.190	....	....	....	
		13.936	15.560	17.188	15.561	3.252	....	Thread dist.
5	5	7.374	8.990	10.600	....	....	....	F. S. = 26.550
		7.364	8.974	10.586	....	....	....	B. S. = 26.547
		7.369	8.982	10.593	8.981	3.224	....	I = 53.097
								Ex.F.S. = +0.06m.
6	1	3.716	5.298	6.880	....	....	....	
		3.716	5.296	6.880	....	....	....	
		3.716	5.297	6.880	5.298	3.164	....	
7	5	10.962	12.634	14.300	....	....	....	
		10.960	12.630	14.298	....	....	....	
		10.961	12.632	14.299	12.631	3.338	....	
T. B. M. 129	1	23.548	25.140	26.730	....	....	22.8	4.30 P. M.
		23.542	25.134	26.722	....	....	....	Delayed 60 min.
		23.545	25.137	26.726	25.136	3.181	....	by rain.
					112.384	26.550		

Lake St. Clair, Mich., by D. Molitor, 1899.

(*Left-hand page.*)

TABLE No. 13.—REVERSE LINE

JULY 5TH, 1899.

BACK SIGHTS.

Point.	Rod No.	Thread readings.			Mean.	Thread distance.	Temp.	Remarks.
		1	2	3				
		dcm.	dcm.	dcm.	dcm.	dcm.	deg. C.	5.30 P. M.
T. B. M. 129.	1	23.514	25.108	26.694	....	....	22.2	Cloudy, calm.
		23.522	25.112	26.704	....	....	....	Light rain.
		23.518	25.110	26.699	25.109	3.181	....	Reading good.
T. P. 1.....	5	10.864	12.536	14.204	....	....	....	
		10.864	12.536	14.202	....	....	....	
		10.864	12.536	14.203	12.534	3.339	....	
2.....	1	3.754	5.338	6.916	....	....	....	
		3.756	5.336	6.918	....	....	....	
		3.755	5.337	6.917	5.336	3.162	....	
3.....	5	7.214	8.828	10.442	....	....	....	
		7.220	8.834	10.450	....	....	....	
		7.217	8.831	10.446	8.831	3.229	....	F. S. = + 158.269
								B. S. = − 114.296
4.....	1	14.218	15.846	17.470	....	....	....	+ 43.973
		14.216	15.844	17.472	....	....	....	Res.Cor. + 0.0002
		14.217	15.845	17.471	15.844	3.254	....	
								$R = + 43.9732$
5.....	5	16.596	18.194	19.794	....	....	....	
		16.590	18.192	19.790	....	....	....	Closing error
		16.593	18.193	19.792	18.193	3.199	....	= 0.02 mm.
6.....	1	8.988	10.746	12.504	....	....	....	
		8.982	10.738	13.500	....	....	....	
		8.985	10.742	13.502	10.743	3.517	....	
7.....	5	15.878	17.706	19.540	....	....	....	
		15.876	17.702	19.534	....	....	....	
		15.877	17.704	19.537	17.706	3.660	....	
					114.296	26.541		

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* Taken from precise level line along

T. B. M. 128-T. B. M. 129.* (*Right-hand page.*)

FORE SIGHTS.

Point.	Rod No.	Thread readings.			Mean.	Thread distance.	Temp.	Remarks.
		1	2	3				
		dcm.	dcm.	dcm.	dcm.	dcm.	deg. C.	
T. P. 1.....	5	17.488	19.072	20.654	....	....	....	
		17.496	19.080	20.662	....	....	....	
		17.492	19.076	20.658	19.075	3.166	....	
2.....	1	19.164	20.826	22.486	....	....	....	
		19.164	20.828	22.486	....	....	....	
		19.164	20.828	22.486	20.826	3.322	....	
3.....	5	21.064	22.688	24.304	....	....	....	
		21.064	22.690	24.310	....	....	....	
		21.064	22.689	24.307	22.687	3.243	....	
4.....	1	8.364	9.950	11.534	....	....	....	
		8.370	9.954	11.536	....	....	....	Thread dist.
		8.367	9.952	11.535	9.951	3.168	....	F. S. = 26.528 B. S. = 26.541 I = 53.069
5.....	5	17.938	19.522	21.106	....	....	....	
		17.940	19.522	21.110	....	....	....	Ex. F. S. = 0.26 m.
		17.939	19.522	21.108	19.523	3.169	....	
6.....	1	14.804	16.486	18.170	....	....	....	
		14.800	16.480	18.164	....	....	....	
		14.802	16.483	18.167	16.484	3.365	....	
7.....	5	20.388	22.100	23.814	....	....	....	
		20.380	22.094	23.808	....	....	....	
		20.384	22.097	23.811	22.097	3.427	....	
T. B. M. 128.	1	25.796	27.626	29.462	....	....	21.1	
		25.790	27.622	29.460	....	....	....	
		25.793	27.624	29.461	27.626	3.668	....	6.30 P. M.
					158.269	26.528		Cloudy, calm.

Lake St. Clair, Mich., by D. Molitor, 1899.

(*Left-hand page.*) TABLE No. 14.—EXAMPLE OF PRECISE

Grass River Crossing.

AUG. 22D, 1898. BACK SIGHTS.

Point.	Rod No.	Thread readings.			Mean.	Thread distance.	Temp.	Remarks.
		1	2	3				
		dcm.	dcm.	dcm.	dcm.	dcm.	deg. C.	
		Instrument at C, 1st set.						
T. B. M. A.	5	11.41	12.52	13.64	....	....	23.9	Tel. N., Bub. D.
		11.42	12.53	13.65	....	....	....	" I., " D.
		11.42	12.53	13.65	....	....	....	" I., " R.
		11.42	12.53	13.64	....	....	....	" N., " R.
	Means.	11.418	12.528	13.645	12.530	2.227	....	
		Instrument at C, 2d set.						
T. B. M. A.	5	11.415	12.535	13.64	....	....	....	Same positions of Instr. used on all sets.
		11.42	12.535	13.65	....	....	....	
		11.43	12.54	13.65	....	....	....	
		11.415	12.53	13.645	....	....	....	
	Means.	11.420	12.535	13.646	12.534	2.226	....	
				Means..	12.532	2.226	....	B. S. = + 12.532 F. S. = − 11.294
		Instrument at D, 1st set.						D_1 = + 1.238
T. B. M. A.	5	8.57	19.11	29.68	....	....	....	
		8.63	19.18	29.75	....	....	....	
		8.62	19.19	29.75	....	....	....	
		8.56	19.13	29.69	....	....	....	
	Means.	8.595	19.152	29.718	19.155	21.123	....	
		Instrument at D, 2d set.						
T. B. M. A.	5	8.57	19.14	29.69	....	....	....	
		8.61	19.15	29.72	....	....	....	
		8.62	19.17	29.73	....	....	....	
		8.58	19.14	29.69	....	....	....	
	Means.	8.595	19.150	29.708	19.151	21.113	....	
				Means..	19.153	21.118	....	B. S. = + 19.153
				Total ..	....	23.344	....	F. S. = − 17.672
								D_2 = + 1.481
				Res. C	or. for	Mean of + 2.08 m.	D_1 and ex. F.	D_2 = + 1.3595 S. = + 0.0013
								D = + 1.3608

* NOTE.—Taken from precise level line along St.

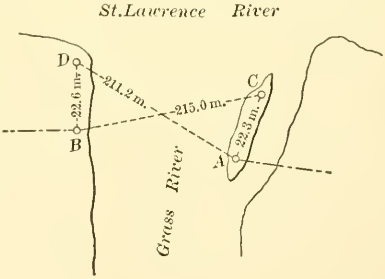

FIG. 16.

LEVEL NOTES FOR A RIVER CROSSING.* (*Right-hand page.*)

Direct Line.

FORE SIGHTS.

Point.	Rod No.	Thread readings.			Mean.	Thread distance.	Temp.	Remarks.
		1	2	3				
		dcm.	dcm.	dcm.	dcm.	dcm.	deg. C.	
T. B. M. B.	1	0.51	11.27	22.01	....	....	....	Weather conditions very favorable; cloudy, calm.
		0.58	11.33	22.09	....	....	....	
		0.58	11.34	22.10	....	....	....	
		0.49	11.28	22.00	....	....	....	4.00 P. M.
	Means.	0.540	11.305	22.050	11.298	21.510	....	
T. B. M. B.	1	0.51	11.28	22.00	....	....	....	
		0.58	11.31	22.09	....	....	....	
		0.58	11.30	22.08	....	....	....	Ratio of telemeter threads 1:100. Value of level tube 5" per 2 mm. Instrument otherwise as above described.
		0.50	11.26	22.00	....	....	....	
	Means.	0.542	11.288	22.042	11.291	21.500	....	
				Means..	11.294	21.505	....	
T. B. M. B.	1	16.54	17.67	18.80	....	....	....	
		16.545	17.675	18.803	....	....	....	
		16.545	17.675	18.802	....	....	....	
		16.54	17.67	18.80	....	....	....	
	Means.	16.542	17.672	18.801	17.672	2.259	....	
T. B. M. B.	1	16.54	17.67	18.80	....	....	23.5	5 P. M.
		16.555	17.675	18.80	....	....	....	
		16.55	17.68	18.802	....	....	....	
		16.54	17.67	18.80	....	....	....	
	Means.	16.546	17.674	18.800	17.673	2.254	....	Thread Dist.
				Means..	17.672	2.256	....	F. S. = 23.761
				Total ..	....	23.761	....	B. S. = 23.344
							Mean...	T. D. = 23.552
							Mean...	ex. F. S. = + 0.208 = + 2.08 m.

Lawrence River, by David Molitor, in 1898.

(*Left-hand page.*) TABLE

Grass River Crossing.*

Aug. 22d, 1898. Back Sights.

Point.	Rod No.	Thread readings.			Mean.	Thread distance.	Temp.	Remarks.
		1	2	3				
		dcm.	dcm.	dcm.	dcm.	dcm.	deg. C.	
			Instrument at *D*, 1st set.					
T. B. M. B.	1	16.34	17.47	18.598	....	....	23.5	Tel. N., Bub. D.
		16.345	17.475	18.60	....	....	....	" I., " D.
		16.345	17.475	18.60	....	....	....	" I., " R.
		16.335	17.47	18.598	....	....	....	" N., " R.
	Means.	16.341	17.472	18.599	17.471	2.258	....	
			Instrument at *D*, 2d set.					
T. B. M. B.	1	16.335	17.465	18.598	....	....	....	Same positions of instr. used on all sets.
		16.34	17.475	18.60	....	....	....	
		16.345	17.475	18.60	....	....	....	
		16.34	17.465	18.598	....	....	....	
	Means.	16.340	17.470	18.599	17.470	2.259	....	
				Means..	17.470	2.258	....	F. S. = + 18.933
								B. S. = − 17.470
								$R_1 = +$ 1.463
			Instrument at *C*, 1st set.					
T. B. M. B.	1	0.75	11.50	22.23	....	....	....	
		0.81	11.54	22.30	....	....	....	
		0.81	11.55	22.31	....	....	....	
		0.71	11.49	22.19	....	....	....	
	Means.	0.770	11.520	22.258	11.516	21.488	....	
			Instrument at *C*, 2d set.					
T. B. M. B.	1	0.75	11.51	22.25	....	....	....	
		0.82	11.56	22.31	....	....	....	
		0.81	11.55	22.30	....	....	....	
		0.73	11.49	22.21	....	....	....	
	Means.	0.778	11.528	22.268	11.524	21.490	....	
				Means..	11.520	21.489	....	F. S. = + 12.766
				Total...	....	23.747	....	B. S. = − 11.520
								$R_2 = +$ 1.246
						Mean of	R_1 and	$R_2 = +$ 1.3545
				Res.	Cor.	for − 2.01	m. ex.	F. S. = + 0.0013
								$R = +$ 1.3558

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* Note.—Taken from precise level line along

No. 15. *(Right-hand page.)*

Reverse Line.

FORE SIGHTS.

Point.	Rod No.	Thread readings.			Mean.	Thread distance.	Temp.	Remarks.
		1	2	3				
		dcm.	dcm.	dcm.	dcm.	dcm.	deg. C.	
T. B. M. A.	5	8.31	18.91	29.47	....	....	....	Weather conditions very favorable; cloudy, calm.
		8.41	18.95	29.52	....	....	....	
		8.40	18.95	29.53	....	....	....	
		8.35	18.91	29.47	....	....	....	
	Means.	8.368	18.930	29.498	18.932	21.130	....	5 P. M.
T. B. M. A.	5	8.33	18.92	29.48	....	....	....	
		8.42	18.97	29.55	....	....	....	
		8.40	18.95	29.52	....	....	....	
		8.32	18.90	29.45	....	....	....	Ratio of telemeter threads 1:100. Value of level tube 5" per 2 mm. Instrument otherwise as above described.
	Means.	8.368	18.935	29.500	18.934	21.132	....	
				Means..	18.933	21.131	....	
T. B. M. A.	5	11.655	12.77	13.87	....	....	23.0	6 P. M.
		11.66	12.77	13.875	....	....	....	
		11.67	12.775	13.88	....	....	....	
		11.655	12.77	13.87	....	....	....	
	Means.	11.660	12.771	13.874	12.768	2.214	....	
T. B. M. A.	5	11.66	12.77	13.87	....	....	....	
		11.655	12.77	13.875	....	....	....	
		11.655	12.77	13.875	....	....	....	
		11.655	12.765	13.865	....	....	....	
	Means.	11.656	12.769	13.871	12.765	2.215	....	Thread Dist.
				Means..	12.766	2.214	....	F. S. = 23.345
				Total...	....	23.345	....	B. S. = 23.747
							Mean...	T. D. = 23.546
							Mean...	ex. F. S. = — 0.201
								= — 2.01 m.

St. Lawrence River, by David Molitor, in 1898.

When a river crossing necessitates a very long sight, it is not advisable to introduce two such sights for the purpose of equalizing back and fore sights, even though the ground would permit of so doing. The corresponding long sight over the ground would in all probability be subject to different refractive influences from those existing over the water surface. Hence, the difference in elevation is determined between two temporary bench-marks *A* and *B* on the respective banks of the river in such a manner as to eliminate all errors of inclination in the line of sight. This is done as follows (see also Fig. 16):

Drive stakes *C* and *D* so that $A\,D = B\,C$ and $A\,C = B\,D$. This is not quite true in the example, but is near enough for the purpose. The direction of the line is from *A* toward *B* and the distances are in meters.

Set up the instrument over *C* and read back sight on *A* and fore sight on *B*, reading as many pairs of sights as conditions may require. Then shift the instrument to *D* and repeat the readings on *A* and *B*. The mean difference of elevation from the two instrument settings eliminates all errors when $A\,D = B\,C$ and $A\,C = B\,D$. Otherwise, a slight correction is applied for the resulting mean excess of fore sight. The same work with sights in opposite directions will constitute the reverse line.

In the example cited, the residual correction for the instrument was + 0.0635 mm. per meter excess of fore sights, and, applying this to the several single lines, gives the differences of elevation from *A* to *B* shown in Table No. 16.

TABLE No. 16.

Line.	Excess of F. S.	Residual correction.	Difference of Elevation.	
			Observed.	Corrected.
1st direct D_1....	+ 215.0 — 22.3 = + 192.7 m.	192.7 × 0.0635 = + 12.24 mm.	+ 123.8 mm.	+ 136.04 mm.
2d direct D_2.....	— 211.2 + 22.6 = — 188.6 m.	—188.6 × 0.0635 = — 11.88 mm.	+ 148.1 mm.	+ 136.22 mm.
1st reverse R_1...	+ 211.2 — 22.6 = + 188.6 m.	188.6 (— 0.0635) = — 11.88 mm.	+ 146.3 mm.	+ 134.42 mm.
2d reverse R_2....	— 215.0 + 22.3 = — 192.7 m.	—192.7 (— 0.0635) = + 12.24 mm.	+ 124.6 mm.	+ 136.84 mm.
		Means.........	+ 135.70 mm.	+ 135.88 mm.

The correction for collar inequality, found by the commonly adopted method of level tube and telescope reversals, was + 0.0235 or a little over one-third of the actual existing error, which is properly accounted for by the residual correction above applied. This also shows a very close agreement of the four values found, which is due to careful work and good weather conditions. Wide river crossings should never be made except during cloudy weather or at sunrise and sunset.

Summary of Results and Index.

Table No. 17 gives an example of a summary of results intended to occupy the last double page of each notebook. This tabulation gives a very comprehensive statement of the work contained in the book, and furnishes directly the data required in the compilation of the final results and computation of elevations.

Results and Elevations.

Table No. 18 serves to illustrate the system adopted for the compilation of results and computation of elevations in the large summary notebook (7 x 9 ins.).

Column 1 gives the number or name of the bench-mark, the elevation of which is found. P. B. M. designates a permanent bench and T. B. M. a temporary bench.

Column 2 gives the bench-mark from which the bench-mark in Column 1 was determined.

Column 3 gives the length of each stretch or distance, in meters, between consecutive bench-marks given in Columns 1 and 2.

Column 4 gives the total length of level line, in kilometers, from the initial point to the bench-mark in Column 1.

Column 5 gives the direction in which the stretch was run. *D* designates direct line or leveled in a direction away from the initial or known point, and *R* designates reverse line, or leveled toward the initial point. *M* represents the arithmetical mean of the accepted results.

Column 6 gives the differences of elevation, in millimeters, between two successive bench-marks, as found by the direct and reverse lines, also the arithmetical mean of the two values. The + sign indicates that the bench found is above the bench from which it was deter-

(*Left-hand page.*)

TABLE No. 17.—Example of

Summary

B. M.		No. of Settings.		Mean thread distance. dcm.	Mean length of stretch. m.	Excess F. S.		Observed Diff. of Elev.	
To	From	D.	R.			D. m.	R. m.	D. mm.	R. mm.
T. 126	T. 125	8	9	43.926	888.7	+0.32	+0.44	—1190.3	—1187.4†
126	125	—	8	43.898	887.6	....	+0.14	....	—1188.8
127	126	9	9	52.784	1066.5	+0.18	+0.46	—2547.2	—2547.1
128	127	6	7	37.346	754.7	+0.02	+0.20	— 548.3	— 547.3
129	128	8	8	53.083	1071.3	+0.06	—0.26	+4397.3	+4397.3
130	129	11	11	70.256	1418.3	+0.02	+1.90	—2258.7	—2258.9
P. 34	130	7	7	32.356	655.5	+0.24	—0.02	+1661.8	+1663.8 † rejected.

*Note.—The final correction applied to all differences of elevation is + 0.063 mm.
excess of F. S. on reverse lines, taking account of the sign of the differ-
The temperature is recorded in degrees Centigrade.
The allowable error of closure for each stretch is $e = 3\sqrt{L}$, where L is the
T = temporary bench-mark; P = permanent bench-mark; P. = afternoon;
The above example is taken from the notes of the precise level line along

mined on the direct line, calling back sights positive and fore sights negative. These signs are reversed on reverse lines, thus giving the same sign to the difference of elevation as found on the direct line. The mean of accepted values is used in computing elevations above datum.

Column 7 gives the residual error from the mean difference of elevation for each stretch.

Columns 8 and 9 give the algebraic summations of these residuals, and show the total discrepancy of each line from the mean, for the entire line from the initial point.

Column 10 gives the probable error in the mean difference of elevation for each stretch as found from the formula $\pm r = 0.674 \sqrt{\frac{\Sigma V^2}{m(m-1)}}$ where V = the residual from the mean for each observation, and m = the number of observations. For a single pair of observations this formula reduces to $\pm r = 0.674\ V$ (see Table No. 25 in the Appendix).

Column 11 gives the probable error r_0 in the elevation of the point, as found from the initial point, and is $\pm r_0 = \sqrt{\Sigma r^2}$. This formula

INDEX PAGE FOR FIELD NOTEBOOKS.* (*Right-hand page.*)

of Results.

CORRECTED DIFF. OF ELEV.		CLOSING ERROR.		Direction of line.	No. of run.	TIME OF DAY.				M. TEMP.		PAGE.	
D. mm.	R. mm.	Actual. mm.	Allow. mm.			D.		R.		D.	R.	D.	R.
						From	To	From	To				
—1190.28	—1187.43†	2.85	2.83	N. 75° E.	1	5.15 P.	6.30 P.	4.00 P.	5.15 P.	30.0	32.2	32	31
....	—1188.81	1.47	2.83	N. 75° E.	2	....	....	6.00 A.	7.15 A.	....	21.1	....	35
—2547.19	—2547.13	0.06	3.08	N. 80° E.	1	6.15 A.	7.45 A.	4.45 A.	6.15 A.	21.1	17.8	30	29
— 548.30	— 547.31	0.99	2.59	N. 70° E.	1	7.00 P.	7.45 P.	4.30 P.	5.30 P.	21.1	18.9	33	34
+4397.30	+4397.32	0.02	3.08	N. 45° E.	1	3.00 P.	5.00 P.	5.30 P.	6.30 P.	23.3	21.7	36	37
—2258.70	—2259.02	0.32	3.56	E.	1	7.00 P.	7.15 A.	5.00 A.	8.00 A.	20.0	20.0	38	40
+1661.82	+1663.80	1.98	2.42	E.	1	5.00 P.	6.15 P.	6.15 P.	7.15 P.	23.3	21.1	42	43
	†rejected												

per meter excess of F. S. for a positive difference of elevation, or — 0.063 mm. per meter ence of elevation as given for the direct line.

length of the single stretch in kilometers and e is in millimeters.
A = forenoon; D = direct line; and R = reverse line.
Lake St. Clair, Mich., by David Molitor, 1899.

is applicable only when all stretches are of equal length, though it is generally used without regard to the actual weights resulting from unequal lengths.

Column 12 gives the mean atmospheric temperature while leveling each stretch.

Column 13 should give the correction to rod length to reduce the latter to standard length and temperature. The law was not yet determined for the rods used.

Columns 14 and 15 give the elevations in meters and feet, respectively, above mean sea level. The history and authority for the determination of the initial bench-mark should follow here.

7. Rules to be Observed on Precise Level Work.

The following axiomatic principles are the result of careful study and observation, and may serve as a guide in answering many of the questions confronting the beginner:

1. Little or no reliance should be placed on an instrument, though it be of the most superior quality. If good results are sought they may be achieved only by constant vigilance and alertness, combined

with most painstaking exertions on the part of the observer, as well as of every member of the party.

2. A line of levels is no better than the poorest portion thereof. Hence the importance of maintaining the same high standards of accuracy on every single rod reading. A slip in one place can never be made good even by the most careful work done thereafter.

3. The shortest line between two terminals is always the best line, provided no unnecessary climbs are encountered thereby. However, it is not advisable to pursue a roundabout route merely to avoid a slight rise or depression. In making a steep descent or ascent it is most advisable to adopt the shortest route perpendicular to the contours, utilizing full rod lengths with minimum lengths of shots. An extra setting costs less delay than to attempt to place rods for proper height.

4. Fore and back sights should always be equal, independent of the nature of the ground leveled over. That is, they should be made so nearly equal as not to require refocusing between reading fore and back sights. Any disturbance of the focusing mechanism would destroy the relative accuracy of readings taken before and after such disturbance. On short sights, the permissible inequality is very small and may frequently require resetting the forward rod. On sights of 50 to 100 m. such inequality may range from 2 to 3 m., but this should not be allowed to accumulate. The sums of sights for an entire stretch should be made exactly equal by properly setting the instrument on the last station.

5. The limiting length of sight for any given instrument and any atmospheric conditions is one for which repeated back and fore sight readings, taken on two fixed points equidistant from the instrument, shall give equal values for the difference of elevation between these points within the attainable limits of accuracy of rod estimations. Ordinarily, good conditions will permit of taking sights of 50 to 70 m., using a 1 to 3-second (per 2-mm. division) level. Very good conditions will permit of reading at 90 m. and exceptionally at 100 m. Fair progress can be made when only 30-m. sights are possible, provided the weather is not too warm, and this limit is solely the result of atmospheric vibrations. Sights exceeding 100 m. should not be taken unless extraordinary precautions are used, such as indicated for a river crossing.

TABLE No. 18.—EXAMPLE OF SUMMARY NOTEBOOK.*

B. M.	Determined from.	DISTANCE.		Direction.	Difference of elevation.	Resid.	ΣV		PROB. ERROR.		Mean Temp.	Rod Cor.	ELEVATION.	
		Partial.	Total.			v	Direct line.	Reverse line.	r ±	r_o ±			Meters.	Feet.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
		m.	klm.		mm.	mm.	mm.	mm.	mm.	mm.	deg. C.	mm.		
T. B. M. 126......	T. B. M. 125	887.6	38.654	*D.*	—1190.28	+0.74	—3.41	+3.41	0.50	3.1	30.0	......	179.18169	587.8717
				R.	—1187.43†	......	......	......	....	....	32.2	......		
				R2.	—1188.81	—0.74	......	......	....	....	21.1	......		
				M.	—1189.54	......	......	.....	....	....	....	......		
T. B. M. 127......	T. B. M. 126	1066.5	39.720	*D.*	—2547.19	+0.03	—3.38	+3.38	0.02	3.1	21.1	......	176.63453	579.5148
				R.	—2547.13	—0.03	......	......	....	....	17.8	......		
				M.	—2547.16	......	......	......	....	....	....	......		
T. B. M. 128......	T. B. M. 127	754.7	40.475	*D.*	— 548.30	+0.50	—2.88	+2.88	0.34	3.2	21.1	......	176.08673	577.7175
				R.	— 547.31	—0.50	......	......	....	....	18.9	......		
				M.	— 547.80	......	......	......	....	....	....	......		
T. B. M. 129......	T. B. M. 128	1071.3	41.546	*D.*	+4397.30	+0.01	—2.87	+2.87	0.01	3.2	23.3	......	180.48404	592.1445
				R.	+4397.32	—0.01	......	......	....	....	21.7	......		
				M.	+4397.31	......	......	......	....	....	....	......		
T. B. M. 130......	T. B. M. 129	1418.3	42.964	*D.*	—2258.70	—0.16	—3.03	+3.03	0.11	3.2	20.0	......	178.22518	584.7335
				R.	—2259.02	+0.16	......	......	....	....	20.0	......		
				M.	—2258.86	......	......	......	....	....	....	......		
P. B. M. 34.......	T. B. M. 130	655.5	43.620	*D.*	+1661.82	+0.99	—2.04	+2.01	0.67	3.2	23.3	......	179.88799	590.1889
				R.	+1663.80	—0.99	......	......	....	....	21.1	......		
				M.	+1662.81	......	......	......	....	....	....	......		
					† Rejected.									

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* Taken from Precise Level Line along Lake St. Clair, Mich., by David Molitor, in 1899.

6. The length of the bubble should be retained practically constant and should be a little over half as long as the graduation.

7. Extreme quiet should prevail about the instrument when work is in progress. The observer calls his readings in quick succession and the recorder should not repeat them back but should test their correctness by careful inspection. This is contrary to general practice, but, in this particular case, it will be found highly commendable.

8. The observer should make it a practice not to remember any readings after he has called them off, as otherwise his memory will frequently deceive him by causing him to call something that he has in mind in place of the real readings which he sees. As in all scientific work, results should be fact and not fiction, and the observer's sole aim should be directed toward obtaining impartial and truthful results, whether these be pleasing or otherwise. The observer must feel absolutely satisfied with every reading taken, and when this is not the case, readings must be repeated until such satisfaction is realized, even though the notes necessitate changes or alterations. A failure to attain perfectly trustworthy readings is always a good cause for the rejection of such work when reasons therefor are given in the remarks.

9. The strict requirement, frequently imposed, regarding the forbiddance to erase, alter or obliterate figures in notes, is not considered a safeguard against fraudulent perpetrations on the part of an observer. Should he have such intention he can easily accomplish his purpose and still comply with all requirements of this kind. If the employer is not willing to accept the final results of his employee, then the latter is not a suitable person to entrust with precise leveling operations.

8. Advantages of the Method Advocated.

The most reliable results in precise leveling are undoubtedly to be obtained by careful and systematic observations designed to prevent and eliminate errors directly in the observations, avoiding, as far as possible, all more or less speculative mathematical manipulations intended to correct and distribute errors inherent in ordinary work and imperfect methods. The labor spent in computing and applying corrections as practiced in the past, when applied to direct elimination of errors in the field, will yield the highest attainable accuracy in the results, without necessarily increasing the cost of the work. This is the fundamental idea in the method described and illustrated.

Furthermore, the readings are so taken and recorded that, by careful inspection, the recorder can always see whether there has been an error in reading or recording. Should any disparity exist, or any irregularity from atmospheric influences be noticeable, the readings can be repeated until a rational set is obtained. This is the secret to the success of this method.

The only disturbing element which cannot be detected in the readings, even though it may be acting, is the warping of the telescope caused by direct and radiated heat in warm weather. This error may, however, be detected by closing each stretch in the same half of the day, and it may be almost entirely eliminated by closing an equal number of stretches forenoons and afternoons.

The office reduction consists merely of compiling results and computing elevations, and no corrections of any kind are necessary save those already applied in the field reduction and checked in the field.

While the ultimate attainable accuracy in precise leveling depends directly on the number of levelings or duplications of work, it is not deemed necessary, from a utilitarian standpoint, to run more than two lines, one direct and the other reverse, thus forming a loop. To go beyond this would result in merely a slight increase in accuracy at a very considerable increase in cost over that for a double line. Thus, three single lines would yield a theoretical accuracy of 1.4 times that obtained from two lines, at 50% increase in cost, and four lines would give an accuracy of 1.7 times that from two lines, at 100% increase in cost.

Hence, conceding the necessity for running duplicate lines, it does not appear practicable to seek greater accuracy by duplicating lines more than twice, and, whatever process of leveling is used, it should be designed with a view of producing the highest accuracy in the results for a single pair of lines. This claim attaches to the method above described.

ACCURACY OF PRECISE LEVEL WORK.

1. The Actual Error of Closure.

The various sources of error have been treated at considerable length in a previous part of this paper. The residual or resultant error of a loop of levels formed by a pair of lines (direct and reverse) will now be discussed.

TABLE No. 19.—Errors in Lines Run Direct

Direct Line.

Back sight.			Fore sight.			Diff. Elevat.	Remarks.
Point.	M. Read.	Th. dist.	Point.	M. Read.	Th. dist.		
	dcm.	dcm.		dcm.	dcm.	mm.	
T. B. M. 128	26.007	3.664	T. P. 1	16.094	3.660	+ 991.3	Cloudy; fresh wind; reading good.
T. P. 1	22.051	3.429	2	10.686	3.526	+1136.5	Cool, puffy wind.
2	16.286	3.363	3	17.997	3.205	— 171.1	Sun out on first set of F. S.
3	19.246	3.193	4	15.561	3.252	+ 368.5	Sun shining; brisk wind.
4	10.100	3.165	5	8.981	3.224	+ 111.9	Cloudy.
5	22.646	3.245	6	5.298	3.164	+1734.8	Cloudy; wind abating.
6	20.919	3.319	7	12.631	3.338	+ 828.8	Delayed 1 hr. by rain.
7	19.102	3.169	T. B. M. 129	25.136	3.181	— 603.4	Cloudy; light wind.
Totals..	156.357	26.547		112.384	26.550	+4397.3	
T. B. M. 129	21.806	3.448	T. P. 1	16.216	3.494	+ 559.0	Cloudy; light wind; reading very good.
T. P. 1	16.640	3.409	2	17.555	3.567	— 91.5	" " "
2	16.838	3.323	3	15.458	3.317	+ 138.0	" " "
3	13.355	3.213	4	17.356	3.014	— 400.1	" " "
4	16.038	3.038	5	20.713	3.068	— 467.5	" " "
5	9.652	3.120	6	20.521	3.207	—1086.9	Cloudy; calm; reading good.
6	15.042	3.239	7	21.216	3.205	— 617.4	" " "
7	15.419	3.149	8	16.151	3.043	— 73.2	Cloudy; light wind.
8	11.213	3.164	9	14.839	3.155	— 362.6	" " "
9	14.487	3.251	10	12.716	3.228	+ 177.1	Partly cloudy; light wind.
10	14.578	2.761	T. B. M. 130.	14.914	2.818	— 33.6	Sun shining.
Totals..	165.068	35.115		187.655	35.116	—2258.7	

Note.—Value of level tube, 2.23″ per 2-mm. graduation; magnifying power of telescope

AND REVERSE, ON PERMANENT TURNING POINTS.

REVERSE LINE.

Back sight.			Fore sight.			Diff. Elevat.	Remarks.	Error. D—R.
Point.	M. Read.	Th. dist.	Point.	M. Read.	Th. dist.			
	dcm.	dcm.		dcm.	dcm.	mm.		mm.
T. P. 7	17.706	3.660	T. B. M. 128	27.626	3.668	+ 992.0	Cloudy; calm; light rain.	—0.7
6	10.743	3.517	T. P. 7	22.097	3.427	+1135.4	" " "	+1.1
5	18.193	3.199	6	16.484	3.365	— 170.9	" " "	—0.2
4	15.844	3.254	5	19.523	3.169	+ 367.9	" " "	+0.6
3	8.831	3.229	4	9.951	3.168	+ 112.0	" " "	—0.1
2	5.336	3.162	3	22.687	3.243	+1735.1	" " "	—0.3
1	12.534	3.339	2	20.826	3.322	+ 829.2	" " "	—0.4
T. B. M. 129	25.109	3.181	1	19.075	3.166	— 603.4	" " "	0.0
Totals..	114.296	26.541		158.269	26.528	+4397.3	Prob. error ± 0.32 mm.	0.0
T.P. 10	16.062	3.480	T. B. M. 129	21.655	3.472	+ 559.3	Partly cloudy; reading good.	—0.3
9	17.441	3.359	T.P. 10	16.524	3.409	— 91.7	Partly cloudy; reading good.	+0.2
8	15.083	3.318	9	16.462	3.330	+ 137.9	Partly cloudy; reading good.	+0.1
7	17.036	3.017	8	13.039	3.211	— 399.7	Partly cloudy; reading good.	—0.4
6	20.277	3.071	7	15.602	3.050	— 467.5	Clear; light wind; reading good.	0.0
5	20.245	3.207	6	9.373	3.122	—1087.2	Clear; fresh wind; reading good.	+0.3
4	20.936	3.202	5	14.761	3.236	— 617.5	Clear; fresh wind; reading good.	+0.1
3	15.889	3.053	4	15.157	3.150	— 73.2	Clear; light wind; reading good.	0.0
2	14.683	3.159	3	11.057	3.165	— 362.6	Clear; light wind; reading good.	0.0
1	12.506	3.217	2	14.277	3.252	+ 177.1	Partly cloudy; reading good.	0.0
T. B. M. 130	14.942	2.800	1	14.604	2.791	— 33.8	Clear; reading good.	+0.2
Totals..	185.100	35.093		162.511	35.188	—2258.9	Prob. error ± 0.32.	+0.2

50 diameters; smallest graduation on rods, 1 cm. Lake St. Clair Levels, 1899.

A very prevalent idea among men of experience in leveling is that the resultant error of closure of a stretch of levels is essentially accidental, being made up of errors of estimation and pointing, and atmospheric disturbances, all of which are considered of a compensating nature. Heaving or settling of rods or instrument have been cited as explanations for errors of a constant nature. Cumulative errors have also been attributed to the personal equation of the observer.

According to the writer's experience, however, the important cumulative error is that produced by the warping effect of the sun's direct and reflected heat rays on the telescope (see experiments in Table No. 6). All other errors are generally of a compensating nature when good instruments are used. Errors due to heaving or settling, when they reach a measurable magnitude, are the result of carelessness, improper instrumental equipment or very unsuitable ground.

To illustrate more conclusively the views here expressed, the levelings in Table No. 19 are given, in which two stretches were leveled over fixed turning points by the method described. The individual thread readings are omitted for the sake of brevity, and only the mean pointings are given. The settings of the reverse lines are given in the order taken on the direct lines, thus offering a more ready comparison.

The weather conditions on the direct line 128-129 were good, though somewhat changeable, while on the reverse line the conditions were uniformly good. This fact, as explained by the remarks, clearly shows the effect of atmospheric changes on the level error. While the error was entirely compensated in the eight instrument settings, yet the difference of elevation between T. P. 1 and T. P. 2 found on the direct line is 1.1 mm. larger than that found on the reverse line.

On the stretch 129-130, the weather conditions were quite uniform, and the partial errors, as also the residual closing error, are all very small, showing that the small final closure is not an accidental balance of large errors, but the result of accurate pointings and close rod estimations, without atmospheric disturbances. This stretch, or any portion thereof, closes within the assigned limits of permissible error for work of the highest grade.

Other data relating to these two lines are given in the example of index page for field notebooks, Table No. 17.

The errors in the two lines 128–129 and 129–130 are entirely of a compensating nature. However, to give an idea of the effect of temperature and atmospheric changes producing cumulative errors, a few other readings are given in Table No. 20, which were taken on the last T. P. 10 and T. B. M. 130, when the sun was higher, but good readings still possible.

TABLE No. 20.

Time, July 6th, 1899.	Difference of elevation, T. P. 10 to T. B. M. 130.	Temp.
	mm.	deg. C.
7.15 A. M.	—33.6*	18.3
7.25 A. M.	—32.7	19.4
7.30 A. M.	—32.2	20.5
8.00 A. M.	—32.2	21.1
4.45 P. M.	—33.8*	26.7

* Accepted.

Such wide differences from the values known to be good cannot escape detection, and, when temperature conditions are such as to produce a marked inclination in the line of sight, the error will always show as a cumulative effect, provided a stretch is closed during the same half of the day.

Many other examples of this kind might be cited to locate the causes of cumulative errors in temperature effects rather than to indulge in a speculative mathematical elaboration intended to show effect of rod supports or personal errors which may or may not be founded on facts.

L. L. Wheeler, M. Am. Soc. C. E., United States Assistant Engineer, in discussing the cumulative errors of precise level work done under the Mississippi River Commission,* attributes these errors almost wholly to personal errors of the observers, and even derives the personal equations of the various observers engaged on this work. These cumulative errors more probably represent the susceptibility to temperature effects of the various instruments used. This presumption seems the more justifiable because a large portion of the work was done during very warm weather and generally in a north and south direction.

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* Annual report of Miss. Riv. Com., 1883, p. 141 *et seq.*

A very fair idea of the accuracy generally attained on precise level work in the United States, and which has not been excelled by other countries, is given in Table No. 21.

TABLE No. 21.—ACCURACY OF PRINCIPAL PRECISE LEVEL WORK IN THE UNITED STATES.

NAME OF LINE.	OBSERVER.	Time of work.	Direction of line.	Length of line.	Prob. error per kilometer.
WORK BY THE UNITED STATES COAST AND GEODETIC SURVEY.					
				km.	mm.
St. Louis, Mo., to New Haven, Mo.	A. Braid	Oct. to Dec. '82.	W.	116.2	±0.83
Mobile, Ala., to Okolona, Miss	J. B. Weir and J. E. McGrath	1884-1886.	N.	423.5	±0.83
Villa Ridge, Ky., to Odin, Ill.	J. B. Weir	Apr.-Jun. '85.	N.	176.0	±0.91
New Haven to Jefferson City, Mo	G. Bradford and I. Winston	Apr.-Jun. '88.	W.	84.4	±0.98
Greenfield, Tenn., to Villa Ridge, Ky.	I. Winston and P. A. Welker	Oct. '88-Jan. '89.	N.	128.1	±1.02
Okolona, Miss., to Greenfield, Tenn.	I. Winston and F. A. Young	Oct. '89-Mar. '90.	N.	265.4	±0.93
Jefferson City, Mo., to Holliday, Kan.	I. Winston and F. A. Young	Apr.-Oct. '91.	N. W.	286.7	±1.47
Corinth, Miss., to Memphis, Tenn.	I. Winston	Nov. '90-Jan. 91.	W.	151.4	±1.05
Old Point Comfort—Richmond, Va.	I. Winston	Dec. '91-Feb. '92.	N. W.	140.5	±1.80
Holliday—Salina, Kan.	I. Winston	Jul.-Oct. '95.	W.	275.9	±0.85
WORK BY THE ENGINEER DEPARTMENT, UNITED STATES ARMY.					
Keokuk, Iowa—Grafton, Ill.	J. B. Johnson and O. W. Ferguson	May-Aug. '81.	S. E.	242	±0.74
Grafton—Cairo, Ill.	J. B. Johnson and O. W. Ferguson	Aug. '80—Mar. '81.	S. E.	346	±1.18
Carrollton, La.—Biloxi, Miss.	Johnson, Ferguson, Paige	Early 1882.	N. E.	140	±0.67
Keokuk, Iowa—Fulton, Ill.	J. B. Johnson and O. W. Ferguson	Sept.-Nov. '82.	N. E.	267	±0.67
Fulton, Ill.—Chicago, Ill.	O. W. Ferguson	May-Aug. '83.	N. E.	261	±0.84
St. Paul, Minn.—Savannah. Ill.	“	May-Oct. '91.	S. E.	484.7	±0.62
St. Joseph, Mo.—Mouth Missouri River	O. W. Ferguson and A. L. Johnson	Mar.-Nov. '92.	S. S. E.	622.5	±0.58
Corinth, Miss.—Decatur, Ala.	O. W. Ferguson and F. B. Williamson	Apr.-Jul. '95.	S. S. E.	173	±0.62
Birmingham, Ala.—Meridian, Miss.	O. W. Ferguson	....	S. W.	......	±0.55
* Gibraltar — Grossepoint, N. Baltimore—Pt. Huron	“	Sept. 21-Dec. 15,'98.	N.	117.6	±0.48
Grossepoint—New Baltimore. Mich.	David Molitor	June, 1899.	N.	43.6 41.0	±0.48 ±0.33
* St. Regis—Oak Point, St. Lawrence River	“ “	Aug. 10-Nov. 1, '98.	S. W.	109.2	±0.61
* Oak Point—Tibbetts Pt., St. Lawrence River	“ “	Nov. 1, '98-Jun. '99.	S. W.	88	±0.48

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* This work was done under the United States Board of Engineers on Deep Waterways.

2. The Probable Error.

Having briefly discussed the actual error of closure found between a pair of direct and reverse level lines, it is intended here to illustrate the extent to which the theory of error is applicable to the subject of leveling.

The formulas for mean and probable errors are applied to precise level work more particularly to give a standard of comparison between different lines and observers. They are also used to furnish a criterion as to the accuracy of the ultimate result of a line of levels.

In reality, however, these formulas serve the purpose intended in a very imperfect manner, being, as they are, only applicable to repeated observations of the same function, taken under similar conditions, and assuming the errors of observation to be strictly of a compensating nature. It is useless to add here that the errors of leveling, and the prevalent conditions producing them, do not morally justify the application of the theory of error to leveling. There is only one excuse for such application, and that is for want of something better.

The theory of error is applicable to observations taken under the same conditions, so that the error of a single observation is as likely to be plus as minus. Also, when comparing groups of observations, each group must contain the same number of observations, and all must be taken under similar circumstances.

In leveling, the principal errors are due to variable conditions which in no way obey natural laws of a constant character. Also, the number of observations forming a group (rod readings in a stretch) differs very widely, thus giving each group a certain weight in the determination of the residual error.

Hence, the essential requirements necessary to render the theory of error applicable are entirely wanting in level observations.

In a general way, however, the errors of leveling, resulting from the above-described system, are more inclined to be compensating than cumulative,and a computation of probable error, while not truly reliable, would nevertheless constitute a fair measure of the average accuracy of a piece of work.

In comparing the accuracy of different lines of levels, it is, of course, necessary to consider the number of instrument settings per kilometer of line as well as the lengths of stretches, because each stretch constitutes a group of observations for which only the algebraic sum of the errors is known and each of the quantities in the group is observed but twice.

It is necessary, therefore, that the stretches be all of the same length and leveled over with a constant length of shot, all of which is impracticable and almost impossible.

Generally, the length of a stretch is determined by the amount of labor or number of settings necessary in covering a certain line, and would imply about 10 to 12 instrument settings, covering from 100 to 1 200 m. The length of shot is chosen to fit the ground and atmospheric conditions for reading, and may vary between 6 and 100 m. It would be practically impossible to assign weights to groups of observations in which such widely different factors constantly enter.

As an illustration, the probable error is computed for the stretch T. B. M. 128 to T. B. M. 129, Table No. 19, in which the errors on the individual turning points were determined (see Table No. 22).

This stretch of 1071.6 m. length, leveled direct and reverse over seven permanent turning points, with eight instrument settings each, closed with a final error of 0.00 mm., and in the computation of Table No. 18, with a closure of ± 0.01 mm. as a result of the correction for excess of fore sights. In the computation of Table No. 22 the probable error is found to be ± 0.517 mm., while for the final closure of the stretch it is only ± 0.003 mm.

A similar computation of the stretch T. B. M. 129 to T. B. M. 130 (length 1418.3 m.) results in a probable error of ± 0.32 mm. (Table No. 19), while the actual error of closure was ± 0.16 mm. (Table No. 18) with a probable error of ± 0.11 mm. This stretch is undoubtedly better than the other, though it has a more detrimental effect on the apparent accuracy of the work.

The inevitable conclusion to be drawn from the foregoing is, as previously stated, that the theory of error is not justly entitled to a place of honor in discussing level errors, though it may be used, as in the past, to give an approximate measure of comparison between different lines.

Assuming, then, that a computation of the probable error of a line of levels is desirable, the formulas previously given will be repeated here, and may be applied with proper reserve.

For a stretch over which m level lines have been run, the probable error in the mean of the m values found for the difference of elevation will be $r = \pm 0.674 \sqrt{\frac{v^2}{m\ (m-1)}}$, in which v is the residual error from the mean for each value. When only two lines (direct or reverse) have been run, then $m = 2$, and the two residuals become equal; hence for this case $r = \pm 0.674 \sqrt{\frac{2\ v^2}{2}} = \pm 0.674\, v$. The values of r for any given values of v may be taken from Table No. 25, in the Appendix.

The probable error per kilometer for any stretch, of length L, in kilometers, is $\pm \frac{r}{\sqrt{L}}$, in millimeters.

The probable error r_0 of a line of levels of length $\Sigma\, L$ is $r_0 = \pm \sqrt{\Sigma\, r^2}$, and the probable error per kilometer is as before $\pm \frac{r_0}{\sqrt{\Sigma\ L}}$.

These formulas are readily solved with any ordinary table of squares and square roots.

TABLE No. 22.—Probable Error of a Stretch of Levels.

B. M.	Determined from	Distance.		Direction.	Difference of elevation.	Resid. v.	$\Sigma\ v$.		Prob. Error.	
		Partial.	Total.				Direct line.	Reverse line	$\pm\ r$.	$\pm\ r_0$.
		m.	m.		mm.	mm.	mm.	mm.	mm.	mm.
T. P. 1	T. B. M. 128	147.7	147.7	D.	+ 991.3	+0.35	+0.35	−0.35	0.236	0.236
		....	....	R.	+ 992.0	......	......	......	......	....
		....	....	M.	+ 991.65	......	......	......	......	....
2	T. P. 1	140.3	....	D.	+1136.5	−0.55	−0.20	+0.20	0.371	0.439
		....	....	R.	+1135.4	......	......	......	......	....
		....	....	M.	+1135.95	......	......	......	......	....
3	2	132.6	....	D.	− 171.1	+0.10	−0.10	+0.10	0.067	0.445
		....	....	R.	− 170.9	......	......	......	......	....
		....	....	M.	− 171.00	......	......	......	......	....
4	3	130.1	....	D.	+ 368.5	−0.30	−0.40	+0.40	0.202	0.488
		....	....	R.	+ 367.9	......	......	......	......	....
		....	....	M.	+ 368.20	......	......	......	......	....
5	4	129.0	....	D.	+ 111.9	+0.05	−0.35	+0.35	0.034	0.490
		....	....	R.	+ 112.0	......	......	......	......	....
		....	....	M.	+ 111.95	......	......	......	......	....
6	5	129.4	....	D.	+1734.8	+0.15	−0.20	+0.20	0.101	0.500
		....	....	R.	+1735.1	......	......	......	......	....
		....	....	M.	+1734.95	......	......	......	......	....
7	6	134.3	....	D.	+ 828.8	+0.20	0.00	0.00	0.134	0.517
		....	....	R.	+ 829.2	......	......	......	......	....
		....	....	M.	+ 829.00	......	......	......	......	....
T. B. M. 129	7	128.2	....	D.	− 603.4	0.00	0.00	0.00	0.000	0.517
				R.	− 603.4	......	......	......	......	....
		1071.6	....	M.	− 603.40	......	......	......	......	....

Note.—For method of computation see explanatory remarks accompanying Table No. 18.

3. The Allowable Error.

In view of the many perplexities attending the results and accuracy of precise level work, the question naturally arises as to what shall constitute acceptable work. This question is not easily answered.

As a general rule, that work is acceptable which is as good as, or better than, has ever been done before. Any work falling within this requirement is certainly beyond adverse criticism. However, certain local and temporary conditions may preclude the possibility of achieving such results, and then it becomes necessary to give an explanation of the reason.

In order that work may be carried on with a uniform degree of accuracy, a certain limit of allowable error is usually stipulated, and whenever a pair of lines does not close within this limit one or more additional lines must be run until a pair (direct and reverse) is obtained which fulfills the requirement. When weather remarks, etc., are carefully noted, the observer will have little difficulty in deciding which one of a pair of lines is most likely to be in error and a third line will usually give an acceptable pair.

According to the law of the continuity of error in a series of observations, the allowable error of closure is made a function of the $\sqrt{L}$, thus, $e = c\sqrt{L}$, assigning various values to c, according to the accuracy desired. In this expression, L is generally taken as the length of the loop line, in kilometers, and e is in millimeters.

The values assigned to the constant c range from 2 to 10, the former being the smallest limit at present attainable, without unnecessarily increasing the cost of the work, when instruments of the highest grade are used. With very good common levels work may be done within the limit $10\sqrt{L}$, though such work cannot be classed with precise levels at this time. The largest limit at present permitted on precise levels is $3\sqrt{L}$.

Some work under the Engineer Department, U. S. Army, has been done within the limit $e = 3\sqrt{L}$, in which L is the length of the single stretch. This limit is very nearly the same as $2\sqrt{L}$ when L is the length of the loop line, which latter is perhaps a better form, and offers a more ready means of comparison.

It follows from the foregoing, that the resulting accuracy of a line of levels, as also the cost and progress of the work, depends almost entirely on the limit assigned, since all work not within such limit must be rejected.

The formula assumes that the error of leveling is purely a function of the length of the line leveled over. It makes no allowance for the fineness of the instrument used, the nature of the ground leveled over, or the length of shot, all of which are important factors which largely govern the magnitude of the closing error.

While it is quite impossible to derive a formula for allowable error which shall include all the variables in their true mathematical relation, the writer ventures to propose a new formula which is intended to give due weight to the principal factors which go to make up the error of closure between a pair of lines.

This formula is $e = c\sqrt{L\sqrt{l}}$ in which L is the length of the loop line, in kilometers; l is the average length of shot, in meters; e is the allowable error, in millimeters; and c is a constant representing the quality of the instrument, and differs for different instruments. Calling v the curvature of the level tube, in seconds per 2-mm. graduation; m the magnifying power of the telescope, in diameters; and t the smallest graduation on the rod, in millimeters; then $c = \sqrt{\frac{v\,t}{m}}$.

As this formula does not make any allowance for atmospheric variations it may be generally accepted only for excellent weather conditions, and errors which exceed this limit are usually the result of poor observing or injurious temperature effects.

As the principal source of error, however, is caused by temperature and atmospheric effects, as previously explained, the foregoing value will be found to be extremely small and difficult to maintain, even on the most careful leveling. It is, therefore, necessary to add a numerical constant k, to cover these errors to the extent desired. The final formula then becomes

$$e = k\sqrt{\frac{v\,t}{m}}\quad\sqrt{L\sqrt{l}} = k\,c\sqrt{L\sqrt{l}}$$

To facilitate the use of this formula, as also those in common use, a diagram, Fig. 17, is given in the Appendix, from which values of e may be read off for any ordinary values of L and l. The diagram is self-explanatory and will be found far more convenient than a tabulation of allowable errors.

4. The Adjustment of Errors.

Whenever a stretch of levels is run in two directions between successive bench-marks, thus forming a closed polygon, the resulting error of closure must be distributed in some manner prior to using the difference of elevation thus obtained in the computation of elevations above datum.

Since there are generally but two measurements (direct and reverse) of the difference of elevation between successive benches, the most probable value is represented by their arithmetic mean. This is quite as true when three or four accepted measurements exist, though this is rarely the case, since a single pair, closing within the stipulated limit, is considered sufficient. The foregoing examples of level notes are reduced in this manner.

When a line of levels closes on itself, thus forming a polygon, the resulting error of the polygon must be distributed over the entire periphery, either in proportion to the length, or, perhaps better, in proportion to the square root of the length, from the known starting point. As there is always more or less guesswork attending such distribution, it matters little which method is adopted.

For large polygons, the spheroidal correction should first be applied to each side before attempting any final distribution of the closing error, as this error may be materially affected thereby.

It sometimes happens that a succession of polygons, or a polygonal system, requires adjustment. Such an adjustment may be made by the method of least squares, as given in some text-books on the "Adjustment of Errors" (Wright and others), or it may be accomplished by a repetition of the method just mentioned for a single polygon, which latter is less laborious and quite within the knowable exactness. All methods applicable to this problem must be regarded as guesswork, be they methodical or otherwise. A good common-sense adjustment is entitled to as much confidence as any other. It is, therefore, deemed unnecessary to add more on this subject.

Rapidity of Work.

The rapidity with which precise level work may be prosecuted is governed by the quality of the work, the training and experience of the party, the grade of the instrumental equipment, the nature of the ground traversed and the weather.

It is, therefore, difficult to give exact information on this subject, though some few facts will enable the reader to make a fair estimate for various conditions under consideration.

With a well-equipped and experienced party, following the method previously described, the average rate of progress over comparatively level country will be about 4.5 km. of single line per day worked. This is for a limiting error of closure $e = 2\sqrt{L}$, in which L is the length of the loop, in kilometers.

The weather conditions generally limit the length of sight to from 30 to 85 m., with an average of about 50 m. This would necessitate from 17 to 6 instrument settings per kilometer of single line. Occasionally, short sights, ranging from 6 to 10 m., are necessitated by undulating ground, in which case the rate of progress becomes very slow.

When the previously described method of observing is followed, the average time required to walk between stations, set up the instrument, and take the readings, is about 9½ minutes. For exceptionally good runs, with clear, steady air and good footing on the road, this time can easily be reduced to 7 minutes, enabling the work to proceed at the rate of about 1 mile an hour. However, 1 km. per hour is very good progress, and, for average conditions of weather and walking, not much over 600 m. per hour will be accomplished. This latter rate represents a good average for a whole field season.

The number of Sundays and days on which weather conditions prevent field work being done can be estimated as between 20 and 25% of the days spent in the field. However, most of this time is well spent in working up the notes and preparing the summary of results, etc.

The average working day will rarely exceed 8 hours, and will generally be about 7½ hours, because the midday hours do not permit of good work being done, except during cloudy weather. This apparently lost time can always be advantageously devoted to the checking of notes.

Table No. 23 will suffice to give a good idea of the work performed in a field season. The St. Lawrence River levels were run by the writer, from August 10th to December 1st, 1898, and from May 1st to June 1st, 1899, for the U. S. Board of Engineers on Deep Waterways.*

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* Final Report of U. S. Board of Engineers on Deep Waterways.

The Lake St. Clair levels were run by the writer in June, 1899, for the Engineer Department, U. S. Army. The former line was generally very undulating, and over poor roads for much of the distance; while the Lake St. Clair line was over good level roads.

TABLE No. 23.—DATA ON RAPIDITY OF WORK.

Item.	St. Lawrence River levels.	Lake St. Clair levels.
Total number of days in the field	135	27
Number of Sundays	20	5
Number of days lost by rain, etc	9.5	0
Number of days actually worked	105.5	22
Number of hours actually worked	746	159
Number of kilometers of single line run	433.55	98.05
Number of kilometers single line per day in field	3.21	3.63
Number of kilometers single line per day worked	4.11	4.46
Number of kilometers single line per hour worked	0.58	0.62
Average time consumed per setting	10.10 min.	9.81 min.
Number of instrument settings, entire work	4 430	972
Average number of instrument settings per kilometer	10.6	9.9
Average length of stretch, in meters	815.7	1 014.4
Average length of shot, in meters	49.0	50.4
Actual closure at end of line, residual from mean	± 1.07 mm.	±2.04 mm.
Residuals passed through zero, times	14	0
Maximum value of residuals, from the mean	±14.72 mm.	±5.44 mm.

COST OF WORK.

The reliable data bearing on this subject are very meager, and must always be used with reserve.

Nearly everyone, intrusted with work of this class, will take pride in producing it as cheaply as possible, yet all high-grade work demands proper pecuniary recognition, and as the cost of leveling is almost entirely a question of salaries, it is readily seen that a wide range is possible, even for the same quality and rate of progress of work.

The factors of weather, season of year, nature of ground covered, etc., all enter, as for rate of progress, though the governing item is liberality in the wages paid.

The average salaries which should be paid to members of a party doing high-class precise level work are about as follows:

Chief of party or observer,	$200	per month	and subsistence	in field.
Recorder	100	"	"	"
Rodmen	60	"	"	"
Umbrellaman	30	"	"	"

This schedule is intended only for the highest grade of precise levels and for experts in that line. Subsistence in the field, when a party subsists on the country, will range from 70 cents to $1.00 per day per man.

Table No. 24 gives the cost of work done by the writer during 1898 and 1899, and may be accepted as a very reasonable expenditure when the quality of the work is considered. The traveling expenses of the party, to and from the field, are excluded, while salaries, subsistence and traveling expenses incidental to the work are all included.

TABLE No. 24.

Item.	Line of Levels Along	
	St. Lawrence River.	Lake St. Clair.
Establishment of permanent bench-marks, each	$4.51	......
Cost of leveling 1 km., single line	5.43	$4.61
Cost of leveling 1 km., direct and reverse	10.86	9.22
Cost of compiling and reducing notes per single kilometer	0.83	0.84

A good average value for estimating total cost of precise level work (exclusive of transportation to and from the field) is about $15 per kilometer, or $24 per mile, of double line.

APPENDIX.

A diagram, Fig. 17, for taking off the allowable error on precise level work, and Table No. 25, for the computation of probable error, are appended. These will serve a good purpose in the field as also in the final compilation of results.

The writer takes this opportunity of expressing his sincere thanks to the U. S. Board of Engineers on Deep Waterways; C. W. Raymond, M. Am. Soc. C. E., Col., Corps of Engineers, U. S. Army; Alfred Noble and George Y. Wisner, Members, Am. Soc. C. E. and members of that Board, and to Colonel G. J. Lydecker, Corps of Engineers, U. S. Army, in charge of the Detroit Office of U. S. River and Harbor Improvements, for granting their kind permission to use some of the data pertaining to the St. Lawrence River and Lake St. Clair Levels.

The writer is also indebted to Professor H. S. Pritchett, former Superintendent, U. S. Coast and Geodetic Survey, for photographs of instruments shown in Plates XXXV and XXXVI.

TABLE No. 25.—Probable Errors for two Observations.

Equation: $\pm r = 0.674\sqrt{\frac{\Sigma v^2}{m(m-1)}} = 0.674\ v$ for two observations; r = probable error, v = residual from mean, m = number of observations.

v.	± *r.*	*v.*	± *r.*	*v.*	± *r.*	*v.*	± *r.*	*v.*	± *r.*
0.01	0.007	0.11	0.074	0.21	0.142	0.31	0.209	0.41	0.276
0.02	0.013	0.12	0.081	0.22	0.148	0.32	0.216	0.42	0.283
0.03	0.020	0.13	0.088	0.23	0.155	0.33	0.222	0.43	0.290
0.04	0.027	0.14	0.094	0.24	0.162	0.34	0.229	0.44	0.296
0.05	0.034	0.15	0.101	0.25	0.168	0.35	0.236	0.45	0.303
0.06	0.040	0.16	0.108	0.26	0.175	0.36	0.243	0.46	0.310
0.07	0.047	0.17	0.115	0.27	0.182	0.37	0.249	0.47	0.317
0.08	0.054	0.18	0.121	0.28	0.189	0.38	0.256	0.48	0.323
0.09	0.061	0.19	0.128	0.29	0.195	0.39	0.263	0.49	0.330
0.10	0.067	0.20	0.134	0.30	0.202	0.40	0.270	0.50	0.337
0.51	0.344	0.61	0.411	0.71	0.478	0.81	0.546	0.91	0.613
0.52	0.350	0.62	0.418	0.72	0.485	0.82	0.553	0.92	0.620
0.53	0.357	0.63	0.425	0.73	0.492	0.83	0.559	0.93	0.627
0.54	0.364	0.64	0.431	0.74	0.499	0.84	0.566	0.94	0.634
0.55	0.371	0.65	0.438	0.75	0.505	0.85	0.573	0.95	0.640
0.56	0.377	0.66	0.445	0.76	0.512	0.86	0.580	0.96	0.647
0.57	0.384	0.67	0.452	0.77	0.519	0.87	0.586	0.97	0.654
0.58	0.391	0.68	0.458	0.78	0.526	0.88	0.593	0.98	0.660
0.59	0.398	0.69	0.465	0.79	0.532	0.89	0.600	0.99	0.667
0.60	0.404	0.70	0.472	0.80	0.539	0.90	0.607	1.00	0.674

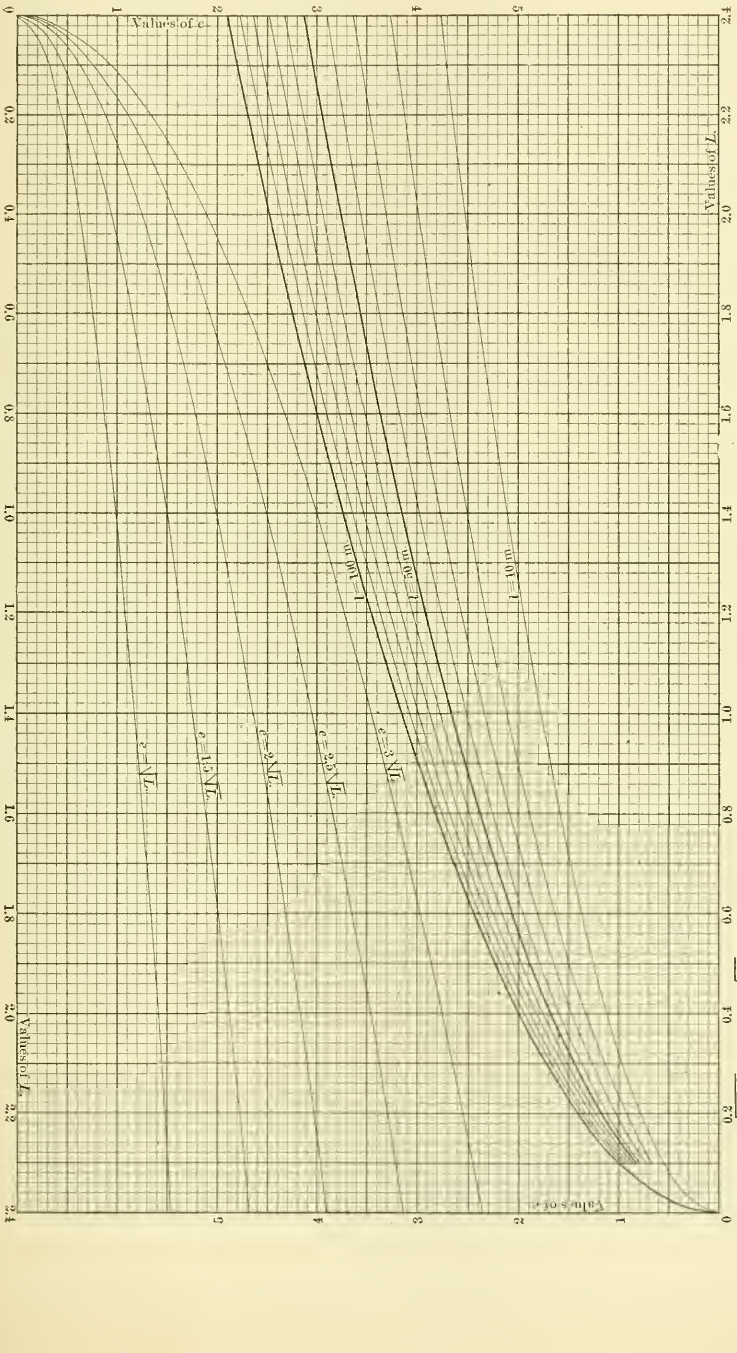

DIAGRAM OF MAXIMUM ALLOWABLE ERRORS IN PRECISE LEVEL WORK.

Fig. 17.

FORMULA: $e=C\sqrt{L}\sqrt{l}$ in which $C=\sqrt{\frac{vt}{m}}$

Above curves are drawn for $C=1$.

L = Length of loopline in kilometers, l = average length of shot in meters, v = seconds, curvature of level per division of 2.0 millimeters

t = Smallest rod graduation in millimeters, m = magnifying power of telescope in diameters, e = error of closure of loop in millimeters.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.
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PAPERS AND DISCUSSIONS.

Note.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

THE PRESERVATION OF RAILWAY TIES IN EUROPE.

By O. Chanute, Past-President, Am. Soc. C. E.

To be Presented October 17th, 1900.

The writer chanced to become engaged practically in the preservation of railway ties by chemical injections, in consequence of his having acted as a member of the Committee which reported to this Society on "The preservation of timber," June 25th, 1885. Having continued in the business fourteen years, he felt the need of information concerning many anomalies which had puzzled him, and thought it desirable that he should investigate the experience and methods of doing the best work in Europe, where the industry has been carried on for the last sixty or seventy years. He accordingly went abroad in October, 1899, and proposes to give to this Society some of the results of his enquiries in three different countries. The same methods are practised in the other countries of Europe.

Great Britain.

England took the lead in preserving timber by chemicals more than one hundred years ago. Her wooden ships forced this subject

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Note.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers with discussion in full will be published in *Transactions*.

upon the attention of her builders and chemists, and thousands of experiments were tried with scores of substances. M. Paulet, in his book, "Conservation des Bois," enumerates 173 processes or methods. Most of them have proved failures, but some four or five proved to have value, as stated in the report of the Committee to this Society in 1885.

These four or five processes were brought into practical use, especially after the "Railway Era" rendered the preservation of ties an important economy, but all antiseptics, save tar-oil, have now been abandoned in England, where "creosoting,"* so-called, has grown to be recognized as the best process to use. Practically all the ties (they call them sleepers) now laid in Great Britain are treated. A few, cut in Scotland, are laid in their natural state, but at least 90% are imported and creosoted.

Mr. S. B. Boulton, author of a paper awarded the Telford medal by the Institution of Civil Engineers in 1884, and universally recognized as the best British authority on the subject; Mr. A. Ross, Chief Engineer of the Great Northern Ry.; Mr. C. L. Morgan, Engineer of the London, Brighton & South Coast Ry.; Mr. Harry Footner, Engineer of the London & North Western Ry., and others, have kindly furnished the writer with data concerning modern British practice, from which the following account has been compiled.

Almost all the sleepers are of "Baltic redwood" from Russia, Sweden and Norway. They are cut in the late autumn or winter, and summer cutting is generally barred in the specifications. The tie makers are generally engaged in farm work during the summer. When the spring and summer floods occur, the sleepers are floated and rafted down the streams to the shipping ports, much of the sap being washed out by this procedure. The logs or ties are then shipped to English ports, arriving some four to six months after felling, and they are frequently left to soak in water until sawed. They are generally imported as "Blocks" or "Balks," cut to a length of 9 ft., and squared to 10 ins., requiring sawing in two, which many railways specify must be done only at the port of delivery. After being made into sleepers, generally 8 ft. 11 ins. long, 10 ins. face and 5 ins. thick, containing 3.11 cu. ft., they are stacked in cribs, with 4-in. spaces between the sleepers and with sloping top layers, and allowed to season from 4 to 6 months more. Thus they are from 10 to 12 months, and sometimes 18 months, old when "creosoted."

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* Creosote, properly so-called, is a medicinal product of vegetable distillation.

Many of the railways have their sleepers adzed and bored for the fastenings by machinery before creosoting, while others do this by hand in laying. It is conceded that boring before treatment is good practice, but sometimes inconvenient when several patterns of chairs are used.

The specification for creosoted sleepers of the London, Brighton & South Coast Ry. is given herewith, in Appendix A, as fairly representing British practice. The mode of injection is practically the same on all roads; the "Bethell" process is used, in which there is no previous steaming, as the sleepers are already well cleared of sap, and seasoned, but the quantities of tar-oil injected and the results differ a little on various roads.

From an elaborate report of M. V. Herzenstein, presented to the International Railway Congress in London, 1895, giving data obtained from about half of the British railways, Table No. 1 has been compiled by the writer. The kind of timber is omitted, as it is almost all "redwood"; and the reported cost, reduced to our money, is only applicable where long contracts previously existed, as tar-oil has much advanced in price since 1894, when the data were gathered. This advance has been due to its increasing recognition as the best timber preservative. Some years ago it was so cheap that it was used as fuel, and while the normal price in England (so far as a fluctuating commodity can be said to have a normal price) was about 4 cents per gallon, it is now 7 cents per gallon, hard to find, and with indications of going higher. The present price increases the cost of creosoting very materially from the prices given in the table.

Most of the railways are getting their creosoting done by contract, but the London and Northwestern is doing its own work, and reports the cost at 20 to 25 cents per sleeper. It also reports the longest life (16 to 20 years), save the London, Tilbury and Southend, which is a small road, of light traffic. The British are not injecting nearly as much tar-oil as the French roads, and they obtain a lesser life, as will be shown later.

Many of the results obtained with sleepers in England are due to the system of track. The rails are of the "Bull-head" type, laid on chairs with about 108 sq. ins. of bearing surface, and hence there is no

TABLE No. 1.—Abstract of Answers of British Railways to Mr. Herzenstein.

Number.	Railway.	Number of sleepers annually renewed	Process of preservation.	Amount injected.	Reported cost, 1894. Cents.	Life, in years.	Cause of failure.
I.....	Belfast and N. Counties Ry	....	Creosoting.	1 gall. per cubic foot.	12	15	Splits.
II....	Furness Ry..........	40 000	"	8 lbs. per cubic foot.	15	15	
III...	Hall Barnoley Ry...	4 000 to 24 000	"	8 lbs. per cubic foot.	......	......	
IV....	Great Eastern Ry...	90 000 to 100 000	"	2½ galls. per tie.	16	12–15	Wear.
V.....	Great Northern Ry..	....	"	0.7 gall. per cubic foot.	13	12	
VI....	Great Southern and Western Ry.	....	"	3½ galls. per tie.	......	......	
VII...	London and North Western Ry.....	300 000	"	30 lbs. per tie.	......	16–20	Wear.
VIII..	London and South Western Ry.....	170 000	"	2½ galls. per tie.	18	12	Wear & splits.
IX....	London, Tilbury and Southend Ry.	Variable.	"	7 to 10 lbs. per cubic foot.	......	25–30	Decay, etc.
X	Manchester S. and L. Ry............	20 per mile.	"	10 lbs. per cubic foot.	......	16	40% Decay.
XI....	Midland Ry..........	....	"	....	......	......	
XII...	North British Ry....	....	"	1 gall. per cubic foot.	14	......	
XIII..	North London Ry...	....	"	28 lbs. per tie.	......	15	
XIV..	South Eastern Ry...	97 000	"	28 lbs. per tie.	......	8–9	Wear.
XV ..	Taff Vale Ry........	17 000	"	1⅓ galls. per cubic foot.	30	15	Natural causes.

Particular attention is called to the quantities (28 to 30 lbs.) of creosote injected per tie. The creosote used practically conforms to the specifications of Dr. Tidy, published in Mr. Boulton's paper, of 1884, and is to be entirely free from water, cone oil, shale oil, or other inferior oils.

cutting by the foot of the rail. The fastenings consist of trenails, of round drift bolts called spikes, and of lag screws, and are thoroughly effective.

France.

France, which was once so abundantly wooded, has been partly denuded, the present area of the forests being estimated at about one-fifth of what it was in the days of Julius Cæsar. The forests have, moreover, been culled, yet they furnish about 3 000 000 ties annually to the French railways, leaving about 1 000 000 to be imported. Of the aggregate about 2 600 000 ties per annum are now consumed in renewals, and it is a notable feature that the number renewed has been diminishing for the past 15 years,* in spite of the fact that the mileage to be maintained has been constantly increasing.

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* The renewals averaged 3 072 605 ties per annum for the eight years 1878 to 1885 inclusive.—H. Mathieu, in *Revue Générale des Chemins de Fer*, August, 1887.

This result, which has been estimated as producing an annual economy of about $3 000 000 to the French railways, has been wholly due to the impregnation of the ties and to constant improvements in the processes. The French began treating wood about 1837 by the "Boucherie" process of expelling the sap by hydraulic pressure, using sulphate of copper as an antiseptic. Many ot the railways took this up, but most of them abandoned it about 1878, and the only road which had continued the use of this substance, the "Midi," has now finally given it up in favor of creosote. The latter substance is now practically used exclusively by all the roads, save those of the State, which use a mixture of chloride of zinc and creosote, which will be more fully noticed when the German practice is described. "Burnettizing," *i. e.*, the injection of chloride of zinc alone, has been extensively used, but is now abandoned, as the zinc is found to wash out in time, especially in moist situations.

The kinds of wood used in renewals and construction have approximately been in the following proportions: Oak, 60%; beech, 22%; pine and sundries, 18 per cent. Of these, the supply of oak is diminishing, and the use of beech and pine is increasing. Formerly, the creosoting of oak was confined to sappy ties, but now all oak is treated, although but small amounts of tar-oil can be forced therein. The quantities of this substance injected have steadily been increased. While the British railways were content with 22 to 30 lbs. per tie, the French railways injected from 31 to 40 lbs. in beech and pine, with correspondingly better results in duration, and they have lately still further increased the amounts. Thus the "Ouest" Railway now requires 44 lbs. per tie; the "Est," which does its own work, injects 60 lbs. of tar-oil per tie, and the "Paris, Lyon et Mediterranée" follows the practice of the "Est."

The results heretofore attained upon the French railways are given in Table No. 2, which is compiled from Mr. Herzenstein's report, already quoted. It will be noticed that the life obtained is considerably in excess of that in England, and is nearly in direct ratio to the quantities injected and to the cost incurred. As this treatment is applied to beech ties, which cost some 70 cents each unprepared; to pine, costing 60 cents each, and to oak, costing from 95 cents to $1.10 each, it is seen that thorough injection produces important economies.

TABLE No. 2.—ABSTRACT OF ANSWERS OF FRENCH RAILWAYS TO MR. HERZENSTEIN.

No.	Railway.	Number of ties annually renewed.	Kind of wood.	Process of preservation.	Amount injected.	Cost. 1893. Cents.	Life, in years	Causes of failure.
XXVII...	State	161 213	Pine.	Zinc. Creosote.	66 lbs. per tie.	....	10–15	Decay.
"	"	....	Oak.	Zinc. Creosote.	9 lbs. per tie.	....	......	
XXVIII..	Eastern........	356 650	Beech.	Creosote.	60 lbs. per tie.	42	25–30	Wear.
XXIX....	Meridional.....	10%	Oak.	None.	....	....	......	
XXX.....	Southern.......	284 511	Pine.	Sulphate of copper	0.4 lb. dry per cubic foot.	....	8–10	Decay and Wear.
"	"	....	Oak.	Creosote.	9.5 lbs. per tie.	....	10–15	Since increased.
XXXI....	Northern.	285 000	Oak.	Creosote.	11 lbs. per tie.	11	......	
"	"	....	Beech.	Blythe Process.	24 lbs. per tie.	21	......	Going over to straight creosoting.
XXXII...	Western.......	242 050	Oak.	Creosote.	11–13 lbs. per tie.	....	15–20	Decay and Splits.
"	"	....	Beech.	Creosote.	31–33 lbs. per tie.	....	18–25 (?)	Now inject 44 lbs.
XXXIII..	Orleans........	460 000	Oak.	Creosote.	12 lbs. per tie.	....	15	Decay.
"	"	....	Pine.	Creosote.	35–44 lbs. per tie.	30	13–16	"
XXXIV..	Paris, Lyon & Mediterranean	700 000 (?)	Oak.	Creosote.	10–11 lbs. per tie.	12	12	Decay and cutting.
"	"	....	Beech.	Creosote.	26–35 lbs. per tie.	18	Prior to 1890.	Now copies Eastern.

All the French roads but one have been creosoting by the "Bethell" process. The exception, the "Nord," has been using the "Blythe" process, which consists in first heating the wood with a mixture of steam and creosote vapor, and then injecting by pressure about 24 lbs. of liquid tar-oil per tie. This method was adopted to economize the amount of this costly substance used. The specifications of this road are given in Appendix B, but the Chief Engineer of Maintenance of Way, Mr. Agnellet, when handing these to the writer, stated that the quantity of creosote injected had lately been increased to 35 lbs. per tie, and that the present cost was 35.6 cents, as against 21 cents per tie in 1893. The road will probably go over to straight creosoting, and adopt the methods of the "Est" Railway, which is recognized as doing the best work of that kind.

The "Est" Railway does its own creosoting, and has two plants with an aggregate capacity of over 500 000 ties a year. It purchases chiefly oak ties (95 cents), and beech ties (65 cents), upon rigid specifications, carefully enforced, and piles them up at its works to season. The piles are isolated and contain 100 ties each, with 10-in. air spaces between the sticks, and the top layer is made of sawed ties laid close and sloping. These piles are inspected from time to time, and if cracks appear a hoop iron **S** is driven in at the end, or a hole is bored and a bolt with washers is inserted. Oak ties are thus seasoned 15 to 20 months, and beech ties 6 months or more, and are further desiccated before treatment in special drying ovens from 60 to 80 hours. Repeated weighings show that the oak loses 16% of its weight in 12 months, and 2.7% more in the drying oven, while the beech loses 25% in 10½ months, and 3.5% more in the ovens. The use of the latter is deemed important, not only to expel remaining moisture and to ensure regularity of treatment, but to obviate the chilling of the hot tar-oil upon its admission. For this purpose, the ties, loaded upon buggies, are run direct from the ovens, where the final temperature is 176° Fahr., into the treating retort, whereupon, without previous steaming, a vacuum of 26 ins. is produced, and the tar-oil then admitted. Before going into the drying ovens the ties are adzed for rail seat and bored for lag-screw fastenings. This is done by steam machinery, at a cost of 2 cents per tie.

The time occupied by a treatment is 2½ hours for oak and 3 hours for beech, of which time ½ hour is under a pressure of 75 lbs. per square inch for oak, and 1 hour of the same pressure for beech, the tar-oil being admitted at a temperature of 176° Fahr. Under these conditions, the oak ties absorb from 14.22 to 16.65 lbs. of creosote each, and the beech ties take from 59.40 to 66.60 lbs. each. More could be forced into the latter, but this has been found sufficient, being, it will be noticed, double as much as is injected in England.

Every invoice of creosote is chemically tested at the works. The requirements are: (1) That it shall be greenish in hue. (2) Naphthalene not over 30%. (3) Distillation not to begin below 392° Fahr. Moreover, there should be 10% of carbolic acid (and attending water) and 10% of green oil, the density of the whole being 1.05 to 1.10 specific gravity. This tar-oil comes generally from the Paris Gas Co., but the specifications cannot be rigidly enforced just now, for tar-oil is so scarce that the engineers have to accept what they can get. The total cost of treatment is 33.8 cents per tie for oak, and 64.2 cents per tie for beech, as stated by M. V. Dufaux, Engineer of Maintenance of Way, of the "Est" System, who kindly gave the writer his elaborate paper, published in "*Revue Générale des Chemins de Fer*" in January and March, 1898. This cost is about double that on other roads, but the results are correspondingly good, the creosoted oak lasting 25 years, and the creosoted beech being estimated to last 30 years in the track, as evidenced by data for 27 years, these data also showing that untreated oak lasts about 15 years.

The road uses "*Vignoles*" or foot rails, and, as already intimated, fastens them to the ties by lag-screws. Tarred tie-plates, of animal felt, have heretofore been in use, but are now replaced by creosoted poplar tie-plates, which cost less than 1 cent each, and are said to be giving perfect satisfaction. Two dating nails are driven in each tie, one at the works, and the other when laid in the track.

GERMANY.

By far the largest proportion of wooden ties laid in Germany are home grown, and almost all are chemically treated before laying. The raw ties of the first class are generally 8 ft. $10\frac{1}{4}$ ins. long, $10\frac{1}{4}$ ins. face and $6\frac{5}{16}$ ins. thick, and cost $1.32 to $1.49 each for oak, and 82 to 90 cents for pine. White beech costs about $1.00 per tie, and red beech is in controversy. About 500 000 oak ties are creosoted annually, and about 1 600 000 pine ties are treated annually with chloride of zinc and creosote for the Prussian State Railway, the whole of Germany probably taking about double those quantities. The German specifications are very strict, and the raw ties are minutely inspected. If there are incipient cracks, a sharpened band of hoop iron, bent into the shape of an **S** is driven in, and the ties are piled up in isolated piles, well ventilated, to season in the receiving yards at the treating works. There they remain, with casual inspection and more driving in of **S**-irons, or insertion of bolts if required, from 8 to 12 months before they are treated, having in the meantime become perfectly seasoned.

At the beginning of the "Railway Era" each railroad company in Germany erected its own works and treated its own ties, either with corrosive sublimate, with sulphate of copper, with chloride of zinc or with creosote, but gradually there was an evolution which curiously recalls that of the Pullman Car Company in the United States. Mr. Julius Rütgers' father, who had learned the business in some French tie-treating works, erected a plant or two, took his son in with him, and did so much better work than the railroads did for themselves that the business gradually came into his son's hands. At the present time, Mr. Rütgers controls some twenty plants, while the Prussian State Railroad has four, and there are five more in other hands.

The general officer in charge of maintenance of way on the Prussian railways told the writer that although the State treated ties at its own works somewhat cheaper than Mr. Rütgers, yet the latter had so much better facilities and controlled the proper quality of chemicals so thoroughly, that it was preferred to give him most of the work by contract, and to operate the State plants as a check. The original reason seems to have been that the railways which did their own work attempted undue economies by skimping the chemicals and employing cheap men, while Mr. Rütgers made a specialty of the business.

Corrosive sublimate and sulphate of copper are now practically given up in Germany, and the State Railway also abandoned Burnettizing or the injection of chloride of zinc by itself in 1897. There are now three processes in use:

(1) Impregnation with chloride of zinc and tar-oil.

(2) Creosoting after seasoning and drying in ovens.

(3) Creosoting after desiccation in hot tar-oil.

The latest German specification (1898) for the first and third of these processes is given in Appendix C. The method of desiccating in hot creosote, although introduced by Mr. Rütgers, was originally proposed by Mr. S. B. Boulton, in England, in 1885.

As the German railways did not answer the questions of Mr. Herzenstein, no such tabular statement can be given as those given herein for England and France, but through the kind assistance of Mr. Rütgers, of Privy Councillor Wetz, of M. F. Holbein, and many others, the important facts were gathered, and access was obtained to many tie-treating plants.

The most notable thing in Germany is the painstaking care with which every operation is performed. The ties are not treated until they are thoroughly seasoned, this generally taking six months to one year after cutting and piling in open piles in the yards, most of which yards will hold one year's supply. The chemicals are tested constantly, a laboratory being attached to each plant, each buggy load of 32 ties is weighed before and after treatment, to make sure that the ties have absorbed enough, and every little while each individual tie of a buggy load is weighed in and out. Thermometers are consulted constantly, and automatic recording gauges preserve a diagram of the vacuum and pressures attained, as well as of their duration; the ties are allowed to dry after treatment before they are placed in the track, and, after they get there, well bedded in deep ballast, further care is exercised to see that they are well drained. The result is that ties prepared by the zinc-creosote process, mostly pine, now last from 12 to 18 years, and creosoted ties, mostly oak, are expected to last from 24 to 28 years. In past time it was not always thus, some beech ties creosoted having perished about as soon as some ties injected with chloride of zinc alone, but the results developed upon the roads in Alsace-Lorraine, where beech ties, creosoted by the French, were found to be sound after 21 years of exposure, have again brought the Germans to favor the use of beech creosoted, there being a surplus of that timber, heretofore disesteemed, in the forests of that country.

An able paper by Mr. A. Schneidt, formerly Superintendent of the Alsace-Lorraine Lines, published in the German Railway Organ in 1896 and 1897, shows that the chloride of zinc undoubtedly leaches out of the ties in time, and he advocates the creosoting of beech wood, either by the process of boiling in hot oil, or by the zinc-creosote process. He shows that the former is the more economical of the two, notwithstanding its greater cost, taking in view the high first cost of the untreated ties in Germany.

The prices paid in Germany for treatment, when reduced to American currency, are shown in Tables Nos. 3 and 4.

TABLE No. 3.

Timber.	With Zinc Chloride.		With Zinc Creosote.	
	1st class. Cents per tie.	2d class. Cents per tie.	1st class. Cents per tie.	2d class. Cents per tie.
Pine	15.60	12.00	19.20	14.40
Oak	12.00	9.12	15.60	12.00
Beech	18.80	12.48	20.40	15.36

TABLE No. 4.

Timber.	With Creosote and Drying Oven.		Boiling in Creosote.	
	1st class. Cents per tie.	2d class. Cents per tie.	1st class. Cents per tie.	2d class. Cents per tie.
Pine	53.76	40.32	56.64	42.00
Oak	26.85	20.16	28.80	21.60
Beech	56.64	42.00	59.28	44.40

These prices are based upon the various amounts of the antiseptics which the different woods absorb, with careful work. As already stated, treatment with chloride of zinc alone has been given up, and boiling in creosote is growing in favor, as computations of annual charges for the renewals exhibit the fact that, notwithstanding the higher cost, impregnation with tar-oil is the most economical, in the long run.

In days gone by, some parties asked for guarantees before having ties treated by the zinc-creosote process, and in such cases Mr. Rütgers guaranteed the following lives:

Guarantee A.

95%	to last	10 years.
80%	"	11 "
70%	"	12 "

Guarantee B.

95%	to last	10 years.
75%	"	11 "
65%	"	12 "
50%	"	13 "
25%	"	14 "

In computing the results, 5% of all ties treated is first deducted, to cover internal diseases which even the strict German inspection cannot detect, and the guarantee applies on the remainder alone, Mr. Rütgers agreeing to make the deficit good to the extent of either refunding the treatment price paid per tie, or treating another tie free of charge, at his option. He charges extra a bonus of 10 pf., or 2.40 cents, a tie for this, and in the case of Guarantee B an extra bonus of 10 pf., or 2.40 cents, a tie a year, for every year's life over the guarantee. In point of fact the character of his work is now so well established that his customers prefer to save the bonus and take their own chances as to life of ties.

Particular attention is called to the German specifications for creosote, and to the amount of chloride of zinc injected in connection therewith. The latter amounts to ½ lb. dry, per cubic foot.

The leading features of tie treatment in Europe are, therefore, the following:

1. Close inspection of raw ties, rejecting all defects.
2. Thorough seasoning for 6 to 12 months before treatment.
3. Constant testing of chemicals; strength, purity, etc.
4. Injection of liberal quantities of the chemicals.
5. Minute care in all the stages of impregnation.
6. Drying the ties after injection.
7. Methods of fastenings superior to our own.
8. Deep ballast, and thorough drainage.
9. Marking with dating nails, and careful records.

UNITED STATES.

Thus it appears that the Europeans are now getting a longer service out of their ties than is obtained in the United States, Mr. Curtis having shown, in his paper* read before this Society May 17th, 1899, that an average life of 10 to 12 years is being obtained by the use of zinc chloride in this country. It would be possible to obtain a life of 15 to 30 years by the use of creosote, but it will be seen, from the figures given, that this would cost three to four times as much as zinc chloride. Thus, at present prices, it would cost 45 cents each to creosote according to English practice, and 15 to 16 years' life would be obtained; it would cost about 85 cents each to creosote after the best French or German practice, and 27 to 30 years' life would be obtained in thoroughly drained ballast; but it would not be economical to spend such sums upon ties costing 20 to 40 cents each untreated, while it is economical to spend them upon ties costing from 90 cents to $1.50 each abroad.

We must be content, therefore, either to allow our cheap ties to decay in the good old way, or to adopt for the present some of the cheaper and inferior methods which will produce shorter lives than obtained in Europe. By the light of past experience, those cheaper methods may be said to be three in number: 1st, straight Burnettizing; 2d, the zinc-tannin process, and 3d, the zinc-creosote process.

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* *Transactions*, Am. Soc. C. E., Vol. xlii, p. 288.

The writer is satisfied that the zinc-tannin process, as modified by himself in 1896, is superior to straight Burnettizing, and that the record of the next few years will demonstrate this, yet he is desirous of doing still better work, and he went abroad chiefly to investigate the zinc-creosote process. He now thinks that it is probably superior to the zinc-tannin process, although part of the greater life shown by records is attributable to other causes, such as the better ballast and drainage, and the better modes of fastening, as well as the climatic conditions. There are, however, some serious difficulties to be overcome before the process can be introduced here. Suitable tar-oil, as described in the specifications of Appendix 3, is just now very scarce and high in price, so high that the freight, the leakage and the cost of the barrels render the cost almost prohibitory. The writer took over with him two samples of American creosote from different makers, and had them analyzed in Berlin, where they were pronounced by Mr. Rütgers' chemist quite unfit for tie preserving by the zinc-creosote process. The writer brought back samples of the German tar-oil, and is now endeavoring to procure a similar product in this country. He is also investigating, so far as he can, the merits of various new processes which are being advanced from time to time, with the hope of finding some method which he can recommend.

The principal dilemma, with reference to new processes, is the fact that it takes half a business lifetime (15 to 18 years) to ascertain beyond peradventure whether an antiseptic or a method is thoroughly efficient to preserve ties in the track; yet it may be possible by isolating the bacteria and fungi which are most destructive to wood, and inoculating chips and shavings with the cultures, to draw some approximate conclusions in the course of a few months. Meanwhile, it is recommended that the railroads shall give trial orders to the various parties who offer plausible processes, and then expose the treated ties in such locations as admit of careful record and watching of the results.

The principal new processes are as follows:

1. The Creo-Resinate Process.—This process was described in a paper presented to this Society by F. A. Kummer, Jun. Am. Soc. C. E., on June 6th, 1900.* He proposes the use of creosote and resin, both preservative substances, to which a small percentage of formaldehyde is to be added. It may be questioned whether the latter volatile substance will stay in the wood, but the process is well worth trying, provided sufficient quantities of the chemicals are injected.

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* *Proceedings*, Am. Soc. C. E., May, 1900.

2. *The Water-Creosote Process.*—This consists in injecting an emulsion of creosote and water, and is being experimented with in Berlin. The writer expects to have samples sent to him this year.

3. *The Hasselman Process.*—This consists in boiling the wood in a solution of the sulphates of copper and iron, with alumina and "Kainit." It possesses the merit of being cheap, and some ties prepared in that way have now been three years in the yard tracks in Berlin. Works have been started at Perth Amboy, N. J., to work this process.

4. *The Allardyce Process.*—This consists in the injection of chloride of zinc, followed by a second injection of tar-oil. A similar process was patented by the late J. P. Card, Assoc. Am. Soc. C. E., in 1882, but neither he nor the writer, who subsequently became his partner, ever succeeded in doing good and regular work therewith, notwithstanding many experiments.

5. *The Naphthenic Acid Process.*—This consists in injecting the wood with a solution of copper which has been dissolved in an acid obtained by a peculiar process in the distillation of Russian petroleum. It is stated to be theoretically effective and cheap, but American petroleum differs so much from the Russian in chemical constituents, that it is yet a question whether the naphthenic acid can be produced in this country.

Laboratory tests are sometimes misleading. They show, for instance, that bichloride of mercury and sulphate of copper, as antiseptics, are superior to chloride of zinc, and yet the latter preserves ties better. So with carbolic acid, which is stated by Mr. Boulton to be less efficient than the heavy oils of creosote. Such criticism, however, does not apply to the laboratory tests of the strength and purity of the materials used, and there are three features of the European practice which it would be well to imitate in this country. They are the following:

1. The careful testing, chemically, of the antiseptics to be injected.
2. The uniform injection of the wood with stated and liberal quantities of the antiseptics.
3. The adequate seasoning of the wood before treatment. This is

now generally neglected in the United States, and yet it is the most important requirement in obtaining good results, for, otherwise, the antiseptic will not be uniformly distributed, and some portions of the ties will decay before others.

Originally, at the works of the writer, ties were treated in the order of their arrival, and without regard to their condition. The result was that in 6 or 7 years some were found to decay much in advance of others. Experiments, made by weighing considerable numbers of individual ties before and after treatment, disclosed the fact that there were great differences in the absorption, and in later years arriving ties have been tested, sorted out, and seasoned in case of need, so as to obtain uniformity of treatment, with the result that the average absorption of chloride of zinc is now two and one-half times as much as it was 14 years ago.

From his experience, the writer is satisfied that if the ties are injected with reasonable uniformity and with the equivalent of ½ lb. of dry zinc-chloride to the cubic foot, as is done in Germany, straight Burnettizing makes them last 10 to 12 years in the track, with ordinary exposure; while perhaps half of that quantity will produce the same result in the more arid regions of the United States; that the new zinc-tannin process will impart to them a life of 12 to 14 years, and the zinc-creosote process may extend this to 14 or 16 years.

It cannot, however, be too strongly insisted upon that the work must be well and skillfully done, for, otherwise, the results are sure to be disappointing.

APPENDIX A.

LONDON, BRIGHTON AND SOUTH COAST RAILWAY COMPANY.

Specification and Conditions of Contract for Creosoted Redwood Sleepers.

1. This proposed contract is for the supply and delivery of

................sleepers at Deptford Wharf,

................sleepers at Newhaven Wharf,

or any less number that the Directors may decide to accept.

2. The dimensions are to be the customary 9-ft. length (say $8\frac{11}{12}$ ft.) 10 by 5 ins. rectangular, cut from square blocks out of which neither more nor less than two sleepers can be sawn (no centers will be accepted).

3. The quality shall be the best Baltic redwood fir in good condition, free from shakes, dead knots, and other defects.

4. Sixty per cent. of the sleepers to have on one side a flat surface not less than 9 ins. wide throughout the length, and the remainder to have on that side a flat surface not less than 8 ins. wide throughout the length. All sleepers to have a flat surface not less than 10 ins. wide on the other side with sharp edges throughout the length.

5. Ninety per cent. of the sleepers to have not less than $8\frac{1}{2}$ ins. and the remainder not less than 7 ins. diameter of heart at both ends.

6. The blocks from which the sleepers are cut must be of last autumn's deflotation at the port of shipment; any delivered of an earlier deflotation will be rejected.

7. The sleepers are to be cut and stacked from four to six months (or until they are considered sufficiently dry by the Company's Engineer or his Inspector) before they are creosoted. They are to be adzed to a true plane for a width of 17 ins. at each end for the chair seating, and 40%, or such other percentage as may be required, are to be bored with eight holes, namely, two $1\frac{1}{8}$ ins. diameter at each end (for trenails) and two $\frac{5}{8}$ in. diameter at each end (for spikes). A template, showing the position of these holes, will be provided by the Company, and the Contractors must bore the holes exact to it, and perfectly true through the sleepers.

8. The sleepers will be inspected at the Contractor's wharf before being creosoted, and the Engineer shall have power, personally or by deputy, to reject any sleepers he may consider inferior, either in quality of timber or from any deviation from the specification, and his decision in the matter shall be final.

9. The sleepers, when sufficiently dry, are to be placed in a wrought-iron cylinder, and when closed a vacuum is to be created by air-pumps. The creosote, at a temperature of 120° Fahr., is to be allowed to enter the exhausted cylinder, and afterward maintained there by pumping at a pressure of not less than 120 lbs. to the square inch. The sleepers are to be kept under this pressure until each sleeper has absorbed at least 3 galls. of creosote on the average, the quantity to be ascertained by weighing.* Any charge of sleepers not giving the average impregnation of at least 3 galls. to be returned to the cylinder for further treatment.

10. The creosote to be a pure coal-tar distillate of the very best quality, free from water and all impurities, and on analysis to give the following results:—

> To be entirely liquid at a temperature of 120° Fahr., and remain so on cooling to 93 degrees.
>
> To contain not less than 25% of constituents that do not distil over at a temperature of 600° Fahrenheit.
>
> To yield, to a solution of caustic soda, not less than 6% by volume of tar acids.
>
> The specific gravity at 90° Fahr. to range between 1.040 and 1.065, water being taken as 1.000 at the same temperature.

11. The Contractor is to supply a copy of the analysis of each delivery of the creosote oil used, in the terms of the Specification, and the Engineer shall be at liberty to take samples of the oil from time to time and have the same tested, the Contractor paying the cost of the analysis to the extent of one analysis for each 10 000 sleepers. Any additional analysis to be made at the Company's expense.

12. Delivery shall be made alongside the Company's New Haven and Deptford Wharves, at either of the rates mentioned below, at the option of the Company's Storekeeper, until the Contract is completed. Delivery at Deptford will be taken by open barges containing not more than 1 800 sleepers each. The craft to take regular turns for discharging, and conform to the regulations of the Company's wharves:—

At Deptford—To commence.............................. and
continue at the rate of .... sleepers per week.
At Newhaven—To commence .... and
continue at the rate of ....sleepers per week.

13. Should the Contractor fail to deliver the sleepers, or any portion of them, as stipulated in Condition No. 12, the Directors may cancel the Contract or the residue thereof, and obtain other supplies in such manner as they think fit, and the Contractor shall pay to the Company any extra cost and expenses incurred by such failure, or the

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* In practice one trolley is weighed out of each charge.—O. C.

Directors may deduct the amount from any sum then due or becoming due to the Contractor.

14. The shipping port or ports must be named in the Tender; and if more than one port, the number of sleepers proposed to be shipped at each port must also be given. Bills of lading to be produced by the Contractor when required.

15. The price per sleeper is to include every charge except wharfage and landing at the Company's wharves.

16. For sleepers delivered and approved during one month, payment will be made at the Company's next monthly pay day by cash, less 2½% discount, provided the Company have no claim on the Contractor as specified in Condition No. 13. In case of any dispute arising between the Contractor and the Company or their agents as to the meaning of any of the terms and conditions of this Contract, the decision of the Company's Engineer shall be final and binding upon all parties.

17. The Contractor shall, if required, enter into and sign a formal Contract with the Directors, and find good and sufficient surety to guarantee its proper fulfilment; the expense of such Contract and Bond to be paid by the Company.

18. The Directors do not bind themselves to accept the lowest or any Tender.

19. The Tenders are to be returned by post, addressed to "The Secretary, L., B. & S. C. R., London Bridge, S. E.," and must reach him not later than first post on ....
endorsed on the outside cover "Tender for Sleepers."

Signed,

....

Storekeeper.

General Stores Office,
New Cross, S. E.

APPENDIX B.

NORTHERN RAILWAY COMPANY, FRANCE.

SPECIFICATIONS.—1893.

For furnishing beech ties of usual shape, creosoted by the new "Blythe" process, called Thermo-Carbolization.

Article 1.—The present specifications refer to the furnishing of ordinary ties for the extension and maintenance of tracks upon the Company's various lines.

Article 2.—The ties shall be of beech, creosoted by the new "Blythe" process (called Thermo-Carbolization).

Article 3.—The ties shall be rectangular, or present one of the sections shown in Figs. 1 and 2.

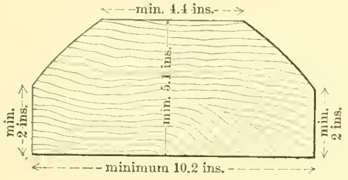

FIG. 1.

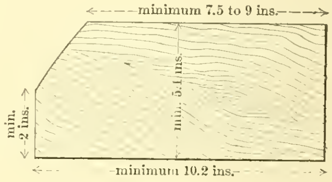

FIG. 2.

The top and bottom faces shall be sawed, the sides may be hewed.

The bottom face, which rests on the ballast, shall be square edged; the two lateral sides shall be without wane, for a minimum height of 2 ins. The top face shall be at least 4.4 ins. wide in the middle, and for the whole length of the tie.

The minimum dimensions of the ties shall be as follows:

Length (2.60 m.)	8.53 ft.
Width (0.26 m.)	10.2 ins.
Thickness (0.13 m.)	5.1 "

Article 4.—The ties shall be practically straight. If bowed sideways the incurvation shall not be more than $\frac{1}{20}$ of the whole length. All ties will be rejected whose bottom face is longitudinally bowed, being either convex or concave.

The ties shall be sawed off square at the ends.

Article 5.—The beech wood must be perfectly sound and of the best quality. It shall be neither heart-shaken, nor frost-split, nor brashy, nor worm-eaten. It shall be exempt from doziness, rotten knots, cracks, splits, bad knots, red-heart or any other defect. The trees shall be felled between the 1st of November and the end of March. They shall be worked up into ties continuously, which work shall be completed by the end of April. Timber will be refused which has been felled before the 1st of November, or not worked up before May 1st.

All the ties shall be completely barked. As fast as the ties are made they must be piled up carefully, cob-fashion. The Chief Engineer of the Company reserves the right of putting on inspectors to follow up the felling and manufacture of the ties at various points.

Article 6.—The untreated ties will all be most carefully inspected, both as to quality and dimensions. Those accepted will be stamped at the ends with the Company's marking hammer.

All the sticks with any dimensions less than the limits stated in Article 3 will be rejected. Those with greater dimensions than required may be accepted, but no allowance will be made for oversize, the ties being purchased by the piece, and not by the cubic meter.

If a tie of good quality, and otherwise acceptable, shows a crack likely to spread open, the Contractor shall bolt the two parts together, or insert an **S** in the end, at his own expense. Every tie split open at the end for its whole width or thickness shall be rejected.

The rejected ties will be left on the hands of the Contractor at the point of inspection; they will be so marked as to preclude them from being again offered for inspection.

Article 7.—The untreated ties must be well seasoned before preparation, and, so far as possible, adzed and bored by the Company, to fit the rails and the lag screws. The seasoning will be tested by weighing a number of ties haphazard. The weight of the timber, thus ascertained, must not be more than 46.7 lbs. per cubic foot.

Article 8.—The ties will be injected with creosote by the new "Blythe" process, called "Thermo-Carbolization." In this process the ties are subjected to the two following operations:

1. They are enclosed in a cylinder of boiler plate and subjected to a current of steam mixed with creosote oil vapor for a length of time sufficient to insure, during the second operation, the absorption of the prescribed quantity of creosote.

2. The cylinder containing the ties is then filled with a sufficient quantity of crude creosote. This liquid, maintained at a temperature of at least 140° Fahr., is compressed in the cylinder by steam to five atmospheres from the generator, during a sufficient length of time so that the total quantity of creosote injected into the wood, both as a vapor and as a liquid, shall be at least 24.4 lbs.* per tie.

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* Since increased to 35.2 lbs. per tie.

If the Engineer of the Company deems it advisable to increase this quantity of creosote, the Contractor will comply with the indications which he may receive relating thereto.

Article 9.—The creosote shall consist of the mixture of volatile products heavier than water distilled from coal-tar produced by gas-works. It shall contain at least 6% of carbolic acid, or of analogous products soluble in caustic soda. It shall be entirely soluble in benzine, and completely liquid at a temperature of 122° Fahrenheit. It must, moreover, conform to the samples which the Contractor shall submit to the Company's Engineer.

The Contractor shall specify from what gas-works each shipment of creosote is received.

Article 10.—The Company shall take cognizance of all the operations relative to the inspection of the wood, through an inspector appointed by the Chief Engineer. Such Inspector shall satisfy himself as to the thorough application of the "Blythe" process, shall keep accounts of the wood injected, and shall verify the results of the injection. He will report, upon a special blank, the following points for each operation:

1. The length of time of application of the mixed steam and oils coming from the vaporizer, as well as the final pressure in this operation, which must be at least five atmospheres.

2. The time occupied in filling the cylinder with crude creosote, the final pressure and the quantity of liquid absorbed during this operation.

3. The quantity of crude creosote introduced in the vaporizer and in the lower reservoir. This quantity shall not be less, for ten consecutive operations, than an average of 24.2 lbs. per tie injected.

4. Finally, the inspector shall keep an exact account of the total quantity of creosote which the Contractor shall receive at the works for injection, so as to check the amount of liquid absorbed during each season's work.

The Chief Engineer of the Company reserves, moreover, the right of using any other checks which he may deem desirable to control the quantity of creosote injected into the wood, either as a mixture of vapors or in the liquid state.

The royalties to be paid to Mr. Blythe or others for the use of the patents, etc., will be at the sole charge of the Contractor, who guarantees the Company against any claim of this nature.

All experiments made by the Company to ascertain whether the creosote is of good quality, and if the injection of the wood is complete, shall be at the charge of the Contractor.

Article 11.—Upon being withdrawn from the cylinder the ties shall be inspected one by one in order to ascertain whether the injection is homogeneous and whether the quantity of 24.2 lbs. has been duly absorbed by each. This last verification shall be effected as described in Section 3 of Article 10.

Such ties as may be incompletely injected, a fact which shall be established by cutting into them with a gouging adze, shall be subjected to a second operation, or even to a third, after which they may be declared, in case of need, as unfit for injection, and finally rejected, as well as those ties which may be deformed by the action of heat in the cylinder.

The Contractor shall make no extra charge for these repeatings of treatment, and shall, moreover, either insert a bolt or an **S** into any tie which shall split during the treatment.

The ties accepted shall be counted and either immediately loaded on cars or piled up at some point designated by the Company's agent. The ties rejected shall receive a special mark at the rail seat and will be piled at special points to be indicated to the Contractor. These ties shall only be taken away upon authority given by the Engineer of the Company, who may hold them until the season's contract is filled, so as to avoid their being again presented for inspection by agents.

Article 12.[*]—The final acceptance of the ties shall only take place six months after the full delivery of the season's contract.

Until this final acceptance the Company reserves the right of rejecting any ties which may possess defects not detected upon a first inspection, or which may split by reason of a bad quality of wood.

The ties so rejected will be surrendered to the Contractor at the point of delivery, who shall either deduct them from his bill or furnish other ties if required by the Company.

Article 13.—The Contractor shall be governed, save in such modifications as result from the present specifications, by the clauses and general conditions imposed upon contractors doing work for the Northern Railway Company, through the Rules drawn up September 26th, 1892, by the Chief Engineer of the Ponts et Chaussées, Chief Engineer of Maintenance of Way, approved October 21st, 1892, by the Executive Committee of said Company, and registered in Paris the 28th of the same month.

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[*] The same contractor furnishes the ties and treats them.

APPENDIX C.

IMPERIAL RAILWAYS OF ALSACE-LORRAINE, GERMANY.

SPECIFICATIONS FOR IMPREGNATING WOODEN RAILROAD TIES.—1898.

Section 1.—For pine ties, the impregnating fluid is a solution of chloride of zinc with an addition of coal-tar oil containing carbolic acid; for beech or oak ties hot coal-tar oil containing carbolic acid must be used.

Section 2.—The process of impregnating by chloride of zinc solution, with addition of coal-tar oil containing carbolic acid, is divided into three parts.

1. Steaming of the ties.
2. Production of a partial vacuum and admission of the impregnating fluid.
3. Compression (forcing in) of the impregnating fluid.

The ties are loaded on iron cars, which are pushed into the impregnating cylinder, this is closed air-tight, and they are exposed to the action of steam; steaming is continued for a longer or shorter period, according to the time of year and the condition of the ties. The admission of steam into the impregnating cylinder must be regulated in such manner, that an inside pressure of 1.5 atmospheres (22 lbs. per square inch) above air pressure is reached within 30 minutes. For dry ties it will suffice to maintain this pressure in the impregnating cylinder for 30 minutes longer, but for green ties it should be kept up for another hour. For dry ties, therefore, the steaming takes at least 1 hour, while for green ties at least 1½ hours are necessary. A gauge attached to the cylinder indicates existence of the specified pressure. The valve at the bottom of the cylinder must be opened on admitting the steam, in order that the air contained in it may be driven out, but should be closed when steam begins to blow out. This valve should be opened repeatedly, as fast as steam condenses; open it at least every half-hour to draw off the water, and for the last time just before exhausting the air. When steaming is finished, the steam remaining in the impregnating cylinder is allowed to escape.

After steam is discharged a partial vacuum is produced in the cylinder containing the ties, until the vacuum gauge shows at the least a column of mercury of 60 cm. (23.6 ins.); this partial vacuum must be maintained for ten minutes. On expiration of this time, while continually preserving the partial vacuum, allow the impregnating fluid, which meanwhile has been prepared in a separate vessel and heated to at least 65° Cent. (149° Fahr.), to enter the impregnating cylinder, filling it entirely. To prepare the impregnating fluid, add while heating, 1 kgr. of coal-tar oil to every 15 kgr. (6⅔%) of the solution of zinc chloride.

To insure as perfect a mixture of the solution of zinc chloride with the coal-tar oil as possible, an effective stirring apparatus, combined with injection of steam and air, must be applied.

Next, a pressure pump is used to exert an excess of seven atmospheres above air pressure. This pressure to be maintained for not less than 30 minutes; if necessary, continue it for a longer time, until the ties have absorbed a certain amount of impregnating fluid as specified hereafter. The impregnating fluid is then run off.

The chloride of zinc solution intended for impregnating must be as nearly as possible free from foreign substances, and there must be no free acid. An admixture of other metals, notably iron, can only be allowed in a very slight percentage and only if it cannot be avoided in the manufacture. The solution must have a strength of 3.5° Beaumé = 1.0244 specific gravity at a temperature of 15° Cent. (59° Fahr.). The solution contains 1.26% of metallic zinc.

The coal-tar oil used must not contain over 1% of oils that boil below 125° Cent. (257° Fahr.). It must be so little volatile that its boiling point lies mainly between 150° and 400° Cent. (302° and 752° Fahr.). In no case is it permissible to have more than 25% of its weight volatilized below 235° Cent. (455° Fahr.). It must contain at least 20 to 25% of acid substances (creosote or oils resembling carbolic acid) that are soluble in caustic lye of soda of 1.15 specific gravity. The coal-tar oil must be entirely liquid at + 15° Cent. (59° Fahr.), and as much as possible free from naphthaline, so that on evaporation (fractional distillation) produced in a glass vessel in groups of 50° each, it shall leave a residue of not more than 5% of naphthaline. Its specific gravity should not be less than 1.020 at a temperature of + 15° Cent. (59° Fahr.) and should not exceed 1.055. To remove such impurities from the impregnating fluid as are due to the process, suitable settling (clarifying) apparatus should be provided.

The Contractor is required to report where he obtains his supplies of zinc-chloride solution and of coal-tar oil, intended for use, and to furnish samples of the same to the Supply Office of the Imperial Railways at Strassburg in Alsace before commencing to impregnate. He will be permitted to purchase the solution of zinc chloride and the carbolized oil of coal-tar only from such factories whose samples have been approved by the Management of the Railways. The Railway Management reserves the right to test the fluids used at any time.

It is specified that the average absorption of impregnating fluid contained in every charge of the cylinder shall be the following:

A. Absorption of 35 kgr. (77 lbs.) for each tie of the first class, length of 2.70 m. (8.85 ft.).

B. Absorption of 26 kgr. (57 lbs.) for each tie of the second class, length of 2.50 m. (8.2 ft.).

C. Absorption of 310 kgr. per cubic meter (19 lbs. per cubic foot*) for ties of other dimensions.

To determine the amount of impregnating fluid absorbed by the ties, the following method must be adopted:

Weigh all ties on a platform scale placed under roof immediately before steaming them, and again after impregnating when dripping has ceased. The difference in weights equals amount of impregnating fluid absorbed. A deduction of 15 pfennigs per 10 kgr. (16 cents per 100 lbs.) will be made for shortage shown by this weighing test. In case the shortage amounts to more than one-sixth of the absorption specified, the impregnation must be repeated. If, on the other hand, the weighing shows that the ties have absorbed more than the amount specified, a bonus of 15 pfennigs for every 10 kgr. (16 cents per 100 lbs.) will be paid for such increase, up to a maximum of 15 per cent.

Section 3.—The work of impregnating with hot carbolized oil of coal-tar (*i. e.*, oil of coal-tar containing carbolic acid) must be divided into two parts.

1. Drying of the ties, *i. e.*, withdrawing water from them.
2. Introduction of oil of coal-tar under pressure.

The ties are run into the impregnating cylinder and this is closed air-tight. Next, a partial vacuum, equal to at least 60 cm. (23.6 ins.) column of mercury, is produced in the impregnating cylinder and maintained for 10 minutes, and thereupon, while keeping up the vacuum, the hot oil of coal-tar is made to flow in until it rises to a level that will prevent sucking over by the air pumps. The flowing in of the coal-tar oil may be accomplished all at once or at intervals, according to the dryness of the ties. While thus filling up, and afterward, the coal-tar is heated up inside the cylinder to at least 105° Cent. (221° Fahr.), but not higher than 115° Cent. (239° Fahr.), by means of steam coils. This heating should be accomplished during a space of time of not less than 3 hours. When this temperature is reached in the impregnating cylinder, it must be kept up for another hour, either with or without the partial vacuum, as may be judged necessary, in order that the ties may absorb the specified amount of oil of coal-tar.

The impregnating cylinder is connected with a pipe condenser from the instant that filling with hot coal-tar oil commences, and all the

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*3.5° *B.* corresponds to 2.62% dry zinc chloride. Hence, 19 × 2.62% amounts to 0.498 lb. of dry zinc chloride per cubic foot.—O. C.

aqueous vapors driven out of the ties are condensed in this, the water being carried to a tank. This receiver must have a water gauge from which one can read off the amount of water evaporated from the ties.

After the drying of the ties or the extraction of water from them is finished, the impregnating cylinder is filled completely and the pressure pump started, which must produce a pressure of at least 7 atmospheres. This pressure is to be maintained for at least 30 minutes in treating beech ties and 60 minutes for oak ties, unless it proves necessary to prolong the time to obtain the amount of absorption specified. The oil of coal-tar is then drawn off.

The coal-tar oil used must be heavy oil, derived from the distillation of coal-tar, of greenish black color, specific gravity of 1.045 to 1.100 at 15° Cent. (59° Fahr.), boiling point between 150° and 400° Cent. (302° and 752° Fahr.).

While making fractional distillation no oils must pass over below 150° Cent. (302° Fahr.) and not more than 25% of the volume at temperature up to 235° Cent. (455° Fahr.).

The coal-tar oil must contain by volume at least 10% of carbolic acid and, at a temperature of 15° Cent. (59° Fahr.), must be free from naphthalene and show no sediment.

To determine percentage of carbolic acid apply agitation to the oils heated to 400° Cent. (752° Fahr.) with a caustic solution of soda having specific gravity of 1.15. The difference in volume of oil before and after agitation gives percentage of carbolic acid.

The Contractor is required to state source of supply for his coal-tar oil and to furnish samples to the Supply Office of the Imperial Railways at Strassburg before he commences work of impregnation. The coal-tar oil can only be purchased from factories whose samples have been approved by the Railway Management. The Railway Management reserves the privilege of at any time testing the coal-tar oil used.

It is specified that the average absorption of coal-tar oil for every charge of the cylinder shall be:

a. For one railroad tie, 1st class, 2.70 m. (8.85 ft.) long, of oak wood, 11 kgr. (24 lbs.); of beech wood, 36 kgr. (79 lbs.).

b. For one railroad tie, 2d class, 2.50 m. (8.20 ft.) long, of oak wood, 8 kgr. (18.6 lbs.); of beech wood, 28 kgr. (61.6 lbs.).

c. For ties of other dimensions per cubic meter (35.3 cu. ft.), of oak wood, 100 kgr. (220 lbs.); of beech wood, 325 kgr. (715 lbs.).

To determine the amount of coal-tar oil absorbed by the ties, these are weighed before the impregnation and again after it, when dripping of oil has ceased, using a platform scale placed under a roof. The difference in weight is amount of coal-tar oil absorbed. Correct the weight of the ties before impregnation by deducting from it weight of water delivered by condenser to the tank and obtained from the vapors distilled while drying in hot coal-tar oil, as weight of ties is reduced to this extent by drying process. If on examination it is proved that absorption amounts to less than five-sixths of that specified, the impregnation must be repeated.

For every shortage in coal-tar oil shown by above test, a deduction of 50 pfennigs for 10 kgr. (54.5 cts. per 100 lbs.) will be made, but, on the other hand, an increase in absorption will be paid for at the same rate, a maximum of 15% increase being the limit of such payment.

Section 4.—The Contractor is required to give eight days' notice to the Supply Office of the time of intended commencing to impregnate ties, in order that the office may send an official to supervise same. This official must be freely admitted at all times to the plant of the Contractor, and all desired information must be readily furnished him. The Contractor must furnish all necessary appliances, apparatus and labor to make tests without charge.

Section 5.—In case the Contractor does not supply his own ties, the parties furnishing them will be required to deliver f. o. b. cars at the station nearest to the impregnating works, provided they are shipped by rail; ties delivered by wagon or other conveyance will be delivered loaded at storage yards of the factory without charge.

The hauling of ties from the station to factory will be at the expense of the Contractor for impregnation. He has also to provide for unloading, piling and handling of ties as per regulations. The Contractor will be paid for this labor the amount of 8 pfennigs (1.92 cents) for each track tie and 4 pfennigs (0.96 cent) for each switch tie of 1 m. These prices cover the expense of labor and tools required in receiving green ties, as well as that of reloading rejected ties; payment for a tie to be made only once.

Section 6.—The Contractor for impregnating is held liable for all damages and loss of ties that may occur from the time they are delivered to him at the railroad station, or at his works, as long as ties remain at his works. This liability includes losses by fire occurring at the impregnation works and by theft committed while ties remain there. The Contractor must pay the value of all missing ties or of such as become unserviceable previous to their return after impregnation, but is not liable for splitting. He is, however, required to furnish without charge all necessary **S**-hooks and bolts for drawing together the cracks occurring during storage, and has to drive or put these in according to directions of the supervising official.

When ties are turned over to the Contractor for impregnation, they are already supplied with **S**-hooks needed to draw together all existing cracks. Each beech track tie is also fitted with two iron bolts running through it, about 10 cm. (4 ins.), from each end in the direction of its breadth. It is his duty, therefore, to supply, without charge, only such **S**-hooks and bolts as may be needed thereafter, and of the same kind, and to fasten them.

Section 7.—On receiving the green ties they must be piled at the factory in such a way that air will circulate freely around each one. Each pile only to have length and breadth equal to length of one tie, and must contain 100 ties. The lowest layer of ties must rest on solid supports, so that they will never touch the ground. Storage yards must be thoroughly drained and have ditches if needed. Open spaces are to be left between the piles, which spaces must measure 80 cm. (32 ins.) in one direction and have a width of 40 cm. (16 ins.). This piling of ties must be finished at the latest in 14 days from receipt of same. Date of piling to be plainly marked on each pile.

For delay in completing impregnation of ties beyond time fixed by contract, unless previous express and written permission of the Imperial General Management has been obtained, the latter will collect a penalty from Contractor for such delay, amounting to 1% of the Contract value of the unfinished impregnation per week of such delay.

Section 9.—The Railroad Management reserves the right to employ the Contractor for impregnation to adze surface of ties in places for bed-plates of rails, as well as to bore holes for fastenings, if such work becomes neccssary. This work to be done by direction of supervising official and before impregnating.

Strassburg, February....1898.

Imperial General Management of
Railways in Alsace-Lorraine.

Acknowledged: The preceding contract of........................
this day the................ 1......

D.........................
Contractor.

Vol. XXVI. SEPTEMBER, 1900. No. 7.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS AND DISCUSSIONS.

Note.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

EXPERIMENTS ON THE FLOW OF WATER IN THE SIX-FOOT STEEL AND WOOD PIPE LINE OF THE PIONEER ELECTRIC POWER COMPANY, AT OGDEN, UTAH.

SECOND SERIES.

Discussion.*

By Messrs. Charles D. Marx, Charles B. Wing and Leander M. Hoskins.

Messrs. Marx, Wing and Hoskins.

Charles D. Marx, M. Am. Soc. C. E.; Charles B. Wing, Assoc. M. Am. Soc. C. E., and Leander M. Hoskins, Esq.—It seems unnecessary to add to the discussion of the degree of reliability of the results, already given by the writers, in the paper on the experiments of 1897.

The questions raised by Mr. Henny have already been answered so far as the writers are able to answer them. It is possible that they underestimate the importance of exterior measurements of the pipe at the trestles. If so, it is to be regretted that Mr. Henny did not make as complete a set of such measurements as seemed to him desirable. The writers are informed by Chief Engineer Bannister that many measurements of the interior diameter were made after the pipe was built, and that no appreciable departure from the estimated size was found. The writers certainly have no interest in maintaining that wood pipe offers greater resistance to flow than smooth iron pipe. Neither are they in possession of the data requisite for deciding the

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*Continued from August, 1900, *Proceedings*. See February, 1900, *Proceedings*, for paper by Charles D. Marx, M. Am. Soc. C. E.; Charles B. Wing, Assoc. M. Am. Soc. C. E., and Leander M. Hoskins, C. E., on this subject.

Messrs. Marx, Wing and Hoskins.

question. They do, however, feel warranted in the belief that the *a priori* estimates of the capacity of large stave pipes which have been published by some writers are far too great.

It is hard to believe that the elaborate discussions of Mr. Williams and Mr. Fenkell are intended as serious contributions to hydraulic literature. Certainly, no competent engineer is likely to regard seriously the proposition that many "supposedly reliable observations" are proved to be "nothing more than crude approximations," by the fact that they fail to show losses of head varying as the square of the velocity. Neither will conclusions which are based upon this "criterion," as to the change in capacity of the Ogden conduit, or as to the value of the results presented in the paper, be likely to meet with acceptance.

The supposition that the passage of water from the 9-ft. tunnel into the 6-ft. pipe generates a spiral motion sufficient to seriously affect the pressure readings at Station 4, 23 ft. from the tunnel, and to be noticeable even at Station 3, 2 733 ft. from the tunnel, does not appear to the writers to be intrinsically probable, or to be supported by the gauge readings at Stations 3 and 4.

As the discussion brings out somewhat diverse views upon the question of the change of capacity of the conduit between the dates of the two series of experiments, it may be well to refer again to this question.

In the discussion of the degree of reliability of the first series of results,* the fact was emphasized that it is impossible to determine very precise values of the coefficient c for low velocities, the reason being that a given error in the measurement of pressure causes an error in the estimated value of c which is far greater at low than at high velocities. While fully realizing this fact, it was thought best to extend the observations to as low velocities as practicable, not only because it was hoped that these observations might not be wholly without value in themselves, but because of the desirability of comparison with the results recorded by others, many of which, particularly upon stave pipes, have been made at low velocities. It appears, however, to be unsafe to base conclusions as to change of capacity upon the results obtained at velocities less than about 2 ft. per second.

As regards the steel pipe, the observations of 1899 probably show, with a somewhat higher degree of precision than the earlier series, the law of variation of loss of head with velocity. It is believed, however, that both series of results for the higher velocities may be accepted for the purpose of making a fairly correct estimate of the change in capacity of the pipe. The results shown in Table No. 3 indicate that the loss of head for a given velocity was about 13% greater in June, 1899, than in August, 1897.

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* *Transactions*, Am. Soc. C. E., Vol. xl, p. 560.

Messrs. Marx, Wing and Hoskins.

Turning next to the wood pipe results, it must be remembered that the curve of loss of head for the experiments of 1899, shown on Plate XVII, is based wholly upon the observations on the long section of pipe above the tunnel, so that the two curves shown are not directly comparable for the purpose of estimating change of capacity. It cannot be assumed that the two portions of pipe should give identical values of the loss of head per thousand feet of length, especially when the different conditions of curvature are considered. The observations of 1899 on the short section of pipe are not sufficiently numerous to be made the basis of conclusions as to change of capacity. They do, however, show a fair agreement with the results of 1897, the only exceptions to this statement being Groups J and N, both taken at low velocities. The conclusions that appear to be warranted are:

(1) That the capacity of the short section of wood pipe changed only slightly, if at all, during the interval between the two series of experiments; and

(2) That in 1899 there was no important difference in capacity between the two portions experimented on.

The question, suggested by the writers and further referred to by Mr. Kuichling, as to whether the loss of head in the Venturi meters may not have increased, appears not to admit of a certain answer. Some light is perhaps thrown on the question by considering how the general results must be corrected if it be assumed that there has been an increased loss of head in the Venturi proper. This assumption would require the estimated velocities to be decreased, thus increasing the value found for the loss of head at any given velocity. This would imply a greater diminution of capacity of the steel pipe than above estimated, with a like result for the wood pipe. Attention has already been called* to the fact that if it be assumed that the observed increase in the loss of head between the first and third columns of the difference gauge is chargeable wholly to the part of the pipe between the throat and the down-stream section, this increase agrees well with that computed for the 6-ft. steel pipe. The most probable view appears to the writers to be that the Venturi meter coefficient remained practically constant.

The suggestion that the registration of the meters should be tested might well have been accompanied by a suggestion of specific means of accomplishing it. No practicable method occurred to the writers.

Regarding the desirability of examining the interior surface of the conduit, it should be said that the commercial operation of the plant does not admit of a shut-down of sufficient length of time to permit of draining the one mile of steel pipe, much less the five miles of wood pipe, unless damage to the plant should necessitate such draining.

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* *Proceedings*, Am. Soc. C. E., February, 1900, p. 126.

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A PROPOSED METHOD FOR THE PRESERVATION OF TIMBER.

Discussion.*

By J. I. BOGGS, Assoc. M. Am. Soc. C. E.

J. I. BOGGS, Assoc. M. Am. Soc. C. E. (by letter).—In discussing the paper by Walter W. Curtis, M. Am. Soc. C. E., the writer gave the results of some observations on creosoted pine ties along the line of the Houston and Texas Central Railway.† These ties had seen 20 years' service, and it was estimated that fully 80% of the original number was yet in the track. The objections to them were: First, the soft wood used, which permitted the rail to cut into the timber very badly; Second, their high price. Mr. Boggs.

These observations were recently confirmed by M. G. Howe, M. Am. Soc. C. E., the present Engineer of Maintenance of Way, and by G. A. Quinlan, M. Am. Soc. C. E., the General Manager of that road, in a late issue of *Engineering News*. Twenty years ago Bethell's process was still in its infancy, and, owing to its excessive cost, managers hesitated to use it, except to a very limited extent; but with the facts deduced from our past experience, certainly none can justly say that "no process has yet been discovered which can be fully depended upon" for the preservation of timber, and it appears to the writer that the time for hesitation is past, especially when we consider the depleted condition of our forests.

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* Continued from August, 1900, *Proceedings*. See May, 1900, *Proceedings*, for paper on this subject, by F. A. Kummer, Jun. Am. Soc. C. E.

† *Transactions*, Am. Soc. C. E., Vol. xlii, p. 348.

Mr. Boggs. The writer has seen some rotten creosoted piling, but in nearly every case this was caused by the bridge carpenters cutting off the ends of the sticks after the piling was driven and neglecting to apply the hot preservative to the exposed end, thereby permitting it to absorb moisture from the atmosphere for days and sometimes weeks at a time. In other cases this decay may be attributed to the treatment of defective timber.

The writer has never been troubled with rot caused by the checking of the creosoted pine timbers after they were in the structure.

It is unfortunate that a great many of our co-workers imagined the poorest class of timber to be the best for creosoting purposes, because it has given rise to the fallacy that "the timber is much weakened by the process." The fact is, if the timber is properly treated, the dead oil neither adds to nor detracts from its strength; but, in nearly every case, comparisons are made between the very poorest and the very best material, the result being the hastily and erroneously drawn conclusion that "the process weakens" it. The writer has seen "thoroughly creosoted piles sometimes break in handling," but close investigation in each instance has shown that originally they were of the poorest pine, such as is known as the "Loblolly"; that they were stacked in the yard to "dry out" for two or three months before being treated, and were, in fact, rotten before the oil ever touched them.

R. Montfort, M. Am. Soc. C. E., Chief Engineer of the Louisville and Nashville Railway, is in a better position than anyone known to the writer to speak with authority on the action of the teredo on creosoted piles, as his line traverses a number of salt water inlets along the Gulf Coast, and probably owns one of the oldest creosoting plants in the country. It is the writer's impression that he has entirely abandoned treating his piling, and is now protecting it with salt-glazed sewer pipe, as creosoting did not protect against the teredo. The Gulf, Colorado and Santa Fé Railway had a similar experience at Galveston, Tex. About the year 1881 they built a creosoted pile trestle, about 2½ miles long, across Galveston Bay. It lasted about 2 years, and was then rebuilt with elm, which, of course, required constant renewals, at a cost of about $1 000 per month. This continued until 1897, when they rebuilt with creosoted pine, with what results the writer is not in a position to say.

The writer once experimented on pine poles containing nothing but sap. The poles were cut in the spring and completely immersed in fresh water. The following spring they were found to have turned into "lightwood," that is, heavy, resinous, pitch pine. They were then placed in salt water, and, up to the following fall, the teredo had failed to attack them to any material extent; hence the writer believes the use of a percentage of resin in the processes of either Bethell or Burnett would be very beneficial; but, that the dead oil of coal-tar will ever alone protect against the teredo, is, in the light of past events, very doubtful. Mr. Boggs.

The prevailing custom of subjecting only the poorest class of timber to the creosoting process is to be greatly deplored, and when a better material is more extensively used very high results may be confidently expected. The use of very high temperatures will unquestionably kill the germs, but, unfortunately, will kill the fiber of the timber also.

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RECENT STADIA TOPOGRAPHIC SURVEYS: NOTES RELATING TO METHODS AND COST.

Discussion.*

By Messrs. George W. Rafter and William B. Landreth.

Mr. Rafter. George W. Rafter, M. Am. Soc. C. E. (by letter).—As to the cost of the several surveys it may be remarked that, without a full statement, Mr. Landreth's tabulation is somewhat misleading. Thus the total cost of Black River survey was $3 815.47; Salmon River Reservoir, $2 459.05. The cost of Fish Creek Feeder is included in the general cost of feeder lines, which is $13 013.23. It should be understood that the cost of Fish Creek Feeder is for topographic work only, all expense for leveling of every kind is included elsewhere. An understanding of these facts gives to the author's results a somewhat different complexion than they would have if unexplained. The writer, however, wishes to accord Mr. Landreth very high praise. The Salmon River and Fish Creek surveys were largely made during severe winter weather, and are evidence of his great energy, as well as skill in this special line of survey.

Another matter which contributed to the success of the work may be mentioned. Each chief of party was required to report to the office at the end of each week exactly what had been done. These reports took the form shown in Table No. 5, which illustrates Mr. Landreth's work on the Salmon River Reservoir for the month of November. At the end of the month the weekly reports were compiled into a monthly report, and forwarded to the Board.

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* Continued from August, 1900, *Proceedings*. See March, 1900, *Proceedings*, for paper by William B. Landreth, M. Am. Soc. C. E., on this subject.

TABLE No. 5.

Mr. Rafter.

REDFIELD, N. Y., December 1st, 1898.

Report of progress on Survey for Salmon River Storage Reservoir for month of November, 1898.

By WILLIAM B. LANDRETH.

Date.	STADIA.		DISTANCE.		No. Days actual work.	Weather.	Character of ground.
	Stations.	Shots.	Stadia Line.	Base Line.			
Nov. 1	20	110	5 326	3 000	1		
" 2	26	147	6 942	5 400	1		
" 3	15	156	3 705	7 600	1		
" 4	18	146	5 234	3 200	1		
" 5	28	90	11 581	5 600	1	Rain.	
" 6	....	....	......	......	....		
" 7	22	51	5 285	4 300	1		
" 8	21	74	4 763	2 000	1		
" 9	22	38	4 719	2 090	1	Rain.	
" 10	16	20	3 072	......	1	Rain.	
" 11	20	19	4 535	......	1		
" 12	22	28	5 652	......	1	Rain.	
" 13	10	9	3 754	......	1		
" 14	22	27	11 834	3 500	1	Rain.	
" 15	22	44	7 845	......	1	Rain.	
" 16	17	13	5 787	3 000	1		
" 17	25	20	13 275	......	1		
" 18	20	57	13 501	3 000	1		
" 19	15	92	24 788	......	1	Rain.	
" 20	21	37	9 075	......	1		
" 21	17	65	6 225	14 800	1		
" 22	14	60	8 139	......	1		
" 23	21	173	11 043	10 100	1	Snow.	
" 24	20	101	6 587	9 600	1		
" 25	....	....	......	......	....		
" 26	21	109	8 700	5 700	1	Snow.	
" 27	18	143	14 890	4 200	1		
" 28	17	158	3 838	14 400	1		
" 29	19	141	6 657	10 300	1		
" 30	23	63	8 420	14 700	1		
Totals....	552	2191	225 262 42.66 Miles.	126 490 23.95 Miles.	28	....	Estimated: 35% Open, 65% Wooded.

Mr. Landreth.

W. B. LANDRETH, M. Am. Soc. C. E. (by letter).—Referring to Mr. Buck's inquiry regarding corrections for distance in stadia surveys in hilly country; the practice on the work described was to make corrections for distance on all readings between stadia points used in calculating circuits and to disregard them on all shots where the correction was less than 3 ft.

The stadia reduction diagrams used were so drawn that the approximate reduction could be noted at a glance and taken off closely if necessary with little labor. All elevations determined were noted on the maps, as in the general work of the U. S. D. W. Survey, and Mr. Himes has been misled regarding them by their having been omitted by the engraver from the illustrations accompanying the paper, owing to the very small scale used.

Mr. Landreth. The writer is unable to give an explanation for the variation in the cost of the three surveys that is entirely satisfactory to himself, but believes that the percentage of wooded area has a great influence on the cost of the surveys. On the Salmon River and Black River Surveys, with a 10-ft. contour interval, the former, with the larger percentage of wood, cost the most, while the Fish Creek Survey with a wooded area about midway between the others, but with a 5-ft. interval, cost 82% of the former.

The methods used on the U. S. Geological Survey could not have been used to advantage on the Salmon River and Fish Creek Surveys owing to the necessity of doing the field work in the late fall and winter, and it is doubtful if there would have been any saving in cost by using that method on the Black River Survey owing to the 10-ft. interval used, as compared with the 20-ft. interval on the Geological Surveys.

To avoid a possible misunderstanding of the items covered by the table of cost of surveys noted by Mr. Rafter, the writer would state that the cost of the following work is included in the amounts given: Salmon River and Fish Creek surveys, stadia field work and map work; Black River, base line and levels on two-thirds of the territory, stadia field work and map work on all the territory.

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IRRIGATION STUDIES.

Discussion.*

By Messrs. MANSFIELD MERRIMAN and RUDOLPH HERING.

Mr. Merriman.

MANSFIELD MERRIMAN, M. Am. Soc. C. E.—In this paper the word "duty" seems to have been used in two senses which are not exactly the same. It is said that the number of acres irrigated by 1 cu. ft. per second is the duty of water. That appears to be an excellent definition, and one that agrees with the use of the word duty in other branches of engineering; but when it is said that 1 acre of land requires so many acre-feet of water to irrigate it, this is not properly the duty of water, but rather a reciprocal of duty. The speaker has found that in presenting engineering matters to students it is extremely important to have the units very clearly and closely defined, and although this word duty is perhaps the least important of all the units, the speaker believes that it may deserve the remark he has made concerning it.

In this connection, the speaker was glad to note that in the publications of this Society on hydraulic matters the terms "second-foot" or "foot-second," as some people say, are not used. These terms lead to confusion, while "cubic feet per second," which should be always used, is clearly understood by everybody. There are many hydraulic engineers, particularly in the Government employ, who always say

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* This discussion (of the paper by Elwood Mead, M. Am. Soc. C. E., printed in the *Proceedings* for May, 1900) is printed in *Proceedings* in order that the views expressed may be brought before all members of the Society for further discussion.

Communications on this subject received prior to October 26th, 1900, will be printed in a later number of *Proceedings*, and subsequently the whole discussion will be published in *Transactions*.

Mr. Merriman. "second-feet" in designating the discharge of water, which is contrary to the principles of formation of compound units. In such a unit, as a foot-pound, or ton-mile, the meaning of the hyphen is that the two simple units are multiplied together; and in the term "second-feet," it might be natural to think that the number of seconds should be multiplied by the number of feet, which would be absurd. On the other hand the word "per" means division; for instance, "cubic feet per second," means the total number of cubic feet divided by the total number of seconds, and is therefore clearly understood. The term "acre-foot" is an excellent compound unit, formed according to correct principles.

Mr. Hering. RUDOLPH HERING, Vice-President, Am. Soc. C. E.—It seems strange that up to the present time the relationship of irrigation and drainage to agriculture has received so little attention. It is only quite recently that proper observations have been made as to the quantity of water which various crops require at different times. The agricultural experiment stations in the United States have begun to make some observations on that subject, and similar stations in Europe are doing the same. Yet it is hardly possible to get reliable information, except from a few isolated points and regarding a few plants. For instance, in this country, the agricultural station at Madison, Wis., is the only one known to the speaker at which the amount of water required during the different months by a certain crop has been determined, and they have there experimented with scarcely a dozen crops.

The speaker believes that it is very important for the agricultural, irrigation or drainage engineer, to know just what amount of water the different crops need and when they need it, particularly in those sections of our country where there is scarcity of water. It is known that during different stages of growth plants need different quantities of water. For instance, at first, during the period of germination, nearly all plants need more than immediately after they have started to grow. Then, they again need a larger quantity, in fact, the most liberal irrigation, when passing through the flowering stage, and the least quantity during fruiting and maturity, when too much water becomes rather injurious.

As this subject is one which the engineer in this country has to meet occasionally, the speaker, when in Europe this summer, made some inquiries thereon, but found a remarkable dearth of experience there also; yet every station is at work trying to get results on the subject.

There is a correlative subject upon which we also have scarcely any data: Where there is water in the ground which is to serve the roots, the question sometimes arises, how far can the ground-water stand below the roots in order that these may still receive sufficient moisture? In our immediate neighborhood there are at this day suits threatened

Mr. Hering.

for several hundred thousand dollars which depend upon that very fact, as to the relation of the quantity of water needed by certain crops, the capillarity of the soil, and the level of the ground-water. This is a question which we, as engineers, will eventually have to face. As yet there is but little information on the subject, and it is very gratifying indeed to see that certain Government officers at the agricultural stations, and engineers abroad, are now studying this matter which, in our country, in one way and another, represents a great deal of money to agriculturists.

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RECENT PRACTICE IN RAILS.

An Informal Discussion at the Annual Convention, July 3d, 1900.*

SUBJECTS FOR DISCUSSION.

"The Progressive Increase in Weight; the Increase in Hardness, particularly in Carbon; the Sections in most General Use; the effect of changes in Weight, Composition and Section."

By Messrs. WILLIAM R. WEBSTER, J. D. SMELT, JOHN F. WALLACE and SIR LOWTHIAN BELL.

Mr. Webster. WILLIAM R. WEBSTER, M. Am. Soc. C. E.—From Mr. Hunt's discussion one might be led to believe that it was the usual practice to use high carbon steel in our rails. But such is not the case, as is shown by the fifteen American rail specifications given in the table prepared by Committee No. 1, of the American Section of the International Association. This table gives 0.45% to 0.55% carbon for the 100-lb. rails used by many of our railroads.

Most of the rails are rolled to the sections of this Society, the rails of 70 lbs. per yard and under giving better satisfaction than the heavier rails. It seems to the speaker that this difference in results is due more to the higher finishing temperature in rolling the heavier sections of rails than to any other cause. The large mass of metal in the head of the heavier rails carries the heat much longer than the thin

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*The discussion of this subject, for which no formal paper was presented, is continued from the August number of *Proceedings* in order that the views expressed may be brought before all members of the Society for further discussion.

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Mr. Webster.

metal in the flange, and the work of rolling has to be stopped on account of cold flange, when the metal in the head is still too hot. By putting more metal in the flange, to carry the heat, the head of the rail can be finished at a much lower temperature, and a closer grain obtained. This is a matter which the Society could take up and investigate to advantage.

As a check on the finishing temperature in rolling, the speaker suggests that a limiting clause be put in the specifications as to the percentage of shrinkage which will be allowed in a rail, from its finishing temperature in rolling to the normal temperature. This amount of shrinkage in a 30-ft. rail is a good measure of the finishing temperature, and it only remains to prove by experiment just how much shrinkage it is safe to allow. Or, in other words, what finishing temperature should be used to produce the best results.

It has been claimed by some who take an extreme view of the present practice, that we are now "hardening our rails by the carbon and squirting them through the rolls." But, as a matter of fact, we know better to-day than ever before the true bearing of the chemical elements on the physical properties of the steel, and the change of structure due to the mechanical work of rolling or forging at the proper finishing temperature.

The beneficial effects of finishing a heavy rail at the proper temperature are shown in re-rolling heavy rails which have not given good service in use. This is accounted for by the annealing action of the furnace in heating the rails up to a low heat for rolling, thus breaking up the coarse grain, and not heating high enough to form it again, the final work of rolling on the head is at a low temperature, the flange being in a condition to allow this work at the proper temperature.

The report of the English Committee appointed by the Board of Trade "To Enquire into the Loss of Strength in Steel Rails through Use on Railways," will appear shortly, and give us much valuable information. It will, no doubt, be the true starting point for international rail specifications.

Many of our specifications, at the present time, have ear-marks in them showing the suggestion of the manufacturers in one section as against those of another, or suggestions of the makers of basic Bessemer steel as against those making acid Bessemer steel. What is wanted is to get rid of all this and take the whole matter up on its merits from an engineering and metallurgical standpoint. From the present indications it looks as though the International Association for Testing Materials would be invited by the Iron and Steel Institute to hold the next Congress in England in the fall of 1901. It is to be hoped that this will be brought about, as there is no society better fitted to assist in this great work than the Iron and Steel Institute of England.

Mr. Webster. The following is quoted from Appendix VII of the report of the English Committee:

"It is probable that the Board of Trade will expect or desire the Committee to recommend an analysis for the guidance of engineers or manufacturers, which shall, in the judgment and experience of the Committee, be the composition of the steel to ensure a safe and good wearing rail. I therefore suggest, after careful consideration from the points of view of a manufacturer and user, that, exclusive of the iron, a steel rail should have the following range of composition:

	Minimum.		Maximum.
"Carbon	0.35	to	0.50
"Silicon	0.05	to	0.10
"Sulphur	0.04	to	0.08
"Phosphorus	....	to	0.08
"Maganese	0.75	to	1.00

"Mr. Edward P. Martin, of Dowlais, considered these suggested figures with me and approves them.

"(Signed) E. Windsor Richards."

On referring to the report of the American Committee No. 1, we find that the chemical limits in rails from 50 to 75 lbs. were as follows:

Carbon	0.35	to	0.50
Silicon	not over		0.20
Sulphur	....		
Phosphorus	not over		0.10
Manganese	0.70	to	1.05

These recommendations are remarkably close, especially when one considers that the work was done in different countries by these Committees entirely independent of each other, and that in America only acid Bessemer steel is used for rails; while in England both the acid and basic Bessemer steel are used.

The results compared above indicate that the suggestions which have been made, that each country prepare standard or representative specifications for each class of material, can be easily carried out. It is not too much to expect that, at the General Congress of the International Association for Testing Materials, to be held in 1901, each country will present representative specifications, and that international specifications will be agreed upon.

The English Committee have been working at a great disadvantage, as in all cases of broken rails examined they knew nothing whatever of the heat treatment of these rails in rolling, and as this has such a great influence on the final structure of the rail, had it been known it would have accounted for many of the abnormal results referred to in the report. It is to be hoped that the work of the Committee of the

Mr. Webster.

Board of. Trade will be continued, that rails will be rolled under known conditions, and that rails from the same heat of steel will be finished hot, medium and cold, in order to get at the true value of the mechanical work of rolling at different temperatures. This will give valuable information in one of the most important lines of research, which has been too much neglected up to the present time.

Mr. Smelt.

J. D. SMELT, M. Inst. C. E.—The speaker has had occasion recently to advise the Argentine Great Western Railway Company on the relative value of American and British tenders for rails.

The section tendered upon, 72.8 lbs. per yard, was designed by the speaker in 1893, and has been rolled several times since that date in Great Britain and also in the United States. It is shown in full black lines in Fig. 1. The enquiry was issued for rails to be manufactured to the speaker's specification. One of the leading American firms tendered in accordance with the Argentine Great Western section, but in accordance with their standard specification for quality. The differences between the two specifications are shown in the table on Fig. 1, the chief differences being the high phosphorus and silicon of the American specification and the lower tensile strength and elongation, coupled with the somewhat inconsistently easy falling-weight test.

The price per ton quoted by the American firm was considerably lower than the British quotations, and the principal questions to decide were: First, what is the relative durability of 43-ton steel as compared with 38-ton steel; and, secondly, the amount of attendant risk due to the presence of high phosphorus and silicon, which, in a rail with a somewhat thin flange, might be considerable.

With regard to durability, it appeared to be approximately in proportion to the tensile strength, which is, in the speaker's opinion, independent of the means adopted to produce it; that is to say, it matters little whether the high or low tensile strength is due to the difference in temperature of the material during rolling, or to difference in chemical composition. Perhaps Mr. Hunt and other members can give some practical information on the subject.

Another point, to which attention should be directed, is the difference in the American standard sections of 70-lb. rails and fish-plates (shown in dotted lines on Fig. 1), as compared with the sections designed for the Argentine Great Western Railway.

In the Argentine Great Western rail, the speaker allowed for a wear of $\frac{5}{8}$ in., and finds that the depth of the head of the American standard is about $\frac{5}{16}$ in. less, which would appear to indicate about half the life, apart from the difference in tensile strength.

With regard to fish-plates, the Argentine Great Western deep section shown on Fig. 1 was designed to make the joint of equivalent

Mr. Smelt.

Chemical Composition	Argentine Gt. Western	American
Carbon	0.4 to 0.5	0.4 to 0.5
Silicon	up to 0,08	up to 0.2
Sulphur	up to 0.06	up to 0.05
Phosphorus	up to 0.06	up to 0.10
Manganese	up to 1.0	0.7 to 0.9
Falling Weight Test on 3-Ft. Bearings		
Weight of Tup	2240 lbs.	2000 lbs.
Height of Fall	13 ft.	17 ft.
Number of Blows (without fracture)	4	1
Deflection under 1st Blow	2 to 3 ins.	
" " 2d "	4 to 5 ins.	
Tensile Test		
Tensile Strength (Tons per square inch)	43	38
Elongation	12% in 10 ins.	12% in 2 ins.
Contraction of Area	20%	

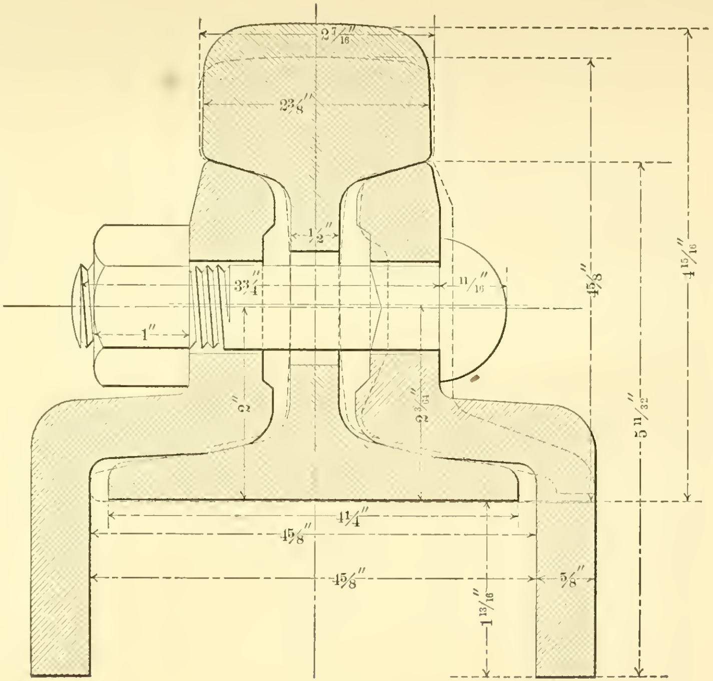

Fig. 1.

strength to the solid rail when worn, and the results of tests prove the design to be correct in this respect. Mr. Smelt.

The American fish-plates of angular design cannot, therefore, be of the same relative strength, especially when taking into account the very soft material of which they are made.

Mr. Wallace. JOHN F. WALLACE, President, Am. Soc. C. E.—Two of the American engineers who have spoken on this question represent inspecting consulting engineers, and one the manufacturers. The speaker would like to say one word from the purchasers' side. The railroads themselves, up to date, have had very little to say about the specifications of the rails used in America, and mainly on account of business reasons. The railways to the east of the Allegheny Mountains have naturally been confined to the use of rails manufactured in that district, first, on account of the fact that the manufacturers were also the customers of the railroads, and produced a great deal of freight and traffic; and secondly, because they were nearer the point of consumption. The same controlling elements exist in the mills in the vicinity of Chicago. The roads of the West, tributary to Chicago, were naturally inclined to purchase rails from the Chicago mills, and the result has been that the roads east of the Allegheny Mountains have been compelled to use rails manufactured in their district, which could be manufactured from the ores east of that point; and the roads in the Mississippi Valley and the West have generally been confined to the use of the rails manufactured in Chicago. A great many roads have endeavored to enforce their own specifications. On the other hand, the mills have endeavored to require the railroads to accept their specifications, coupled with a guarantee that any rails affected during the period of 5 years should be replaced.

The railroads, to-day, through their engineers and their own special organization, which is looking after this particular matter, are now taking up the question of adopting specifications and asking the manufacturers to conform to them. The matter is now in the hands of a Committee of Engineers, who do not propose to draw up specifications which are impossible to fill; but intend to find out, from the character of the ores in different parts of the country, and from the processes of manufacture, what are the possibilities, and will endeavor to decide on specifications which are practical and common-sense. In the formation of such specifications, however, they expect to consult with the manufacturers and with the inspecting engineers.

In reference to phosphorus, some years ago on the Illinois Central Railroad, on a section of road where the traffic was exceedingly heavy, there was in use a 60-lb. rail, laid in 1878. Twenty years after that rail was laid, it was removed in order to replace it with an 85-lb. rail. The rail gave such extraordinarily good service that it was analyzed and found to run as high as 0.012 and 0.015 phosphorus—from 50 to 100% more than the specifications were then calling for.

Sir Lowthian Bell.

SIR LOWTHIAN BELL, M. Inst. C. E.—There are probably few questions connected with the manufacture and behavior of rails while in use which demand a more extended area of examination than those raised by Mr. Hunt. The opinions about to be given are those gathered from many years' experience as a manufacturer supplemented by a still longer experience as a director of one of the most important railroads in the United Kingdom. A life so spent seems to embrace all the conditions essential to the present discussion.

It may be well here to describe the mode of testing used in ascertaining the resistance to fracture offered by the rails under examination:

A weight of one ton (2 240 lbs.), and capable of being detached at any point of its travel, was raised by steam power between two girders

TABLE No. 1.—RESULTS OF TESTS MADE AT PARK LANE STORES, GATES-MIDDLE AND BOTTOM OF INGOTS, AS PER SIR LOWTHIAN BELL'S, 3 FT. APART.

Distinguishing No. of rail......	991		992		993		994		995		996		997		998	
Ingot No.........	1		1		1		2		2		2		3		3	
Part of ingot taken from.....	Top.		Middle.		Bottom.		Top.		Middle.		Bottom.		Top.		Middle.	
	Fall	Def.	Fall	Def.	Fall	Def.	Fall	Def.	Fall	Def.	Fall	Def.	Fall	Def.	Fall	Def.
Results of tests..	ft	ins.	ft	ins.	ft	ins.	ft	ins.	ft	ins.	ft	ins.	ft	ins.	ft	ins.
	5	$\frac{5}{8}$	5	$\frac{11}{16}$	5	$\frac{5}{8}$	5	$\frac{11}{16}$	5	$\frac{5}{8}$	5	$\frac{11}{16}$	5	$\frac{11}{16}$	5	$\frac{11}{16}$
	5	$1\frac{1}{8}$	5	$1\frac{3}{16}$	5	$1\frac{3}{16}$	5	$1\frac{1}{4}$	5	$1\frac{3}{16}$	5	$1\frac{1}{8}$	5	$1\frac{3}{16}$	5	$1\frac{3}{16}$
	7	$1\frac{3}{4}$	7	$1\frac{3}{4}$	7	$1\frac{13}{16}$	7	broke	7	$1\frac{3}{4}$	7	$1\frac{3}{4}$	7	$1\frac{13}{16}$	7	$1\frac{13}{16}$
	10	$2\frac{3}{4}$	10	$2\frac{11}{16}$	10	$2\frac{3}{4}$	..	......	10	$2\frac{11}{16}$	10	$2\frac{5}{8}$	10	$2\frac{3}{4}$	10	$2\frac{3}{4}$
	15	$4\frac{3}{16}$	15	4	15	$4\frac{3}{16}$	..	......	15	$4\frac{1}{8}$	15	$4\frac{1}{16}$	15	$4\frac{1}{8}$	15	$4\frac{3}{16}$
	21	broke	21	$6\frac{1}{8}$	21	$6\frac{7}{16}$	..	......	21	broke	21	$6\frac{1}{4}$	21	broke	21	broke
	..	......	27	broke	27	broke	..	......	..	......	27	$9\frac{15}{16}$	..	......	..	......
	..	......	..	......	..	......	..	......	..	......	27	broke	..	......	..	......
Sum of falling feet (breaking blow halved)...	$52\frac{1}{2}$		$76\frac{1}{2}$		$76\frac{1}{2}$		$13\frac{1}{2}$		$52\frac{1}{2}$		$103\frac{1}{2}$		$52\frac{1}{2}$		$52\frac{1}{2}$	

Note.—These samples taken from

Composition—								
Phosphorus....	0.043	0.048	0.043	0.040	0.044	0.053	0.043	0.050
Sulphur........	0.050	0.060	0.070	0.050	0.060	0.060	0.070	0.060
Carbon	0.560	0.560	0.570	0.500	0.510	0.550	0.560	0.560
Silicon..	0.069	0.066	0.057	0.072	0.072	0.084	0.081	0.069
Manganese	0.950	0.960	0.970	1.020	1.030	1.030	0.950	1.060
Arsenic.........	0.061	0.065	0.061	0.028	0.018	0.044	0.049	0.032
Iron by difference..........	98.267	98.241	98.229	98.290	98.266	98.179	98.247	98.169

The weight of the rail was 90 lbs. per yard, the length tested of considerable height. The usual plan was to raise the weight a very few feet at first, and to increase the height of fall gradually, until fracture was effected. No account was taken of the acceleration of the fall, and therefore of the power, by the continued operation of gravitation, because this did not exhaust by any means the disturbing causes of the calculation. The chief of these is the unknown absorption of power by the deflection of the rail at each blow. The plan followed was to sum up the various falls and count the last at one-half its real amount. The estimate, therefore, is one of comparison only.

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In evidence of irregularity in results the case of the trials of bull-headed steel rails of 90 lbs. per yard may be given. One of these gave way under a united fall of 23 ft., while a second one required for its fracture 199 ft. Chemical analyses of several specimens were made

HEAD, ON 18 PIECES OF NEW "HEMATITE" STEEL RAILS, FROM TOP, INSTRUCTIONS. TESTED JUNE 20TH, 1898; BALL, 1 TON; BEARINGS,

999		1000		1001		1002		1003		1004		1005		1006		1007		1008	
3		4		4		4		5		5		5		6		6		6	
Bottom.		Top.		Middle.		Bottom.		Top.		Middle.		Bottom.		Top.		Middle.		Bottom.	
Fall	Def.	Fall	Def.	Fall	Def.	Fall	Def.	Fall	Def.	Fall	Def.	Fall	Def.	Fall	Def	Fall	Def.	Fall	Def.
ft	ins.	ft	ins.	ft	ins.	ft	ins.	ft	ins.	ft	ins.	ft	ins.	ft	ins.	ft	ins.	ft	ins.
5	$\frac{11}{16}$	5	$\frac{11}{16}$	5	$\frac{11}{16}$	5	$\frac{5}{8}$	5	$\frac{11}{16}$	5	$\frac{5}{8}$	5	$\frac{11}{16}$	5	$\frac{11}{16}$	5	$\frac{5}{8}$	5	$\frac{5}{8}$
5	$1\frac{1}{8}$	5	$1\frac{3}{16}$	5	$1\frac{3}{16}$	5	$1\frac{1}{8}$	5	$1\frac{3}{16}$	5	$1\frac{1}{8}$	5	$1\frac{1}{8}$	5	$1\frac{3}{16}$	5	$1\frac{1}{8}$	5	$1\frac{1}{16}$
7	$1\frac{3}{4}$	7	$1\frac{7}{8}$	7	$1\frac{13}{16}$	7	$1\frac{13}{16}$	7	$1\frac{13}{16}$	7	$1\frac{13}{16}$	7	$1\frac{3}{4}$	7	$1\frac{7}{8}$	7	$1\frac{3}{4}$	7	$1\frac{11}{16}$
10	$2\frac{5}{8}$	10	broke	10	$2\frac{3}{4}$	10	$2\frac{3}{4}$	10	$2\frac{3}{4}$	10	$2\frac{11}{16}$	10	$2\frac{5}{8}$	10	$2\frac{13}{16}$	10	$2\frac{11}{16}$	10	$2\frac{9}{16}$
15	$4\frac{1}{16}$	..	......	15	$4\frac{3}{16}$	15	$4\frac{3}{16}$	15	$4\frac{3}{16}$	15	$4\frac{1}{8}$	15	$4\frac{1}{8}$	15	$4\frac{1}{4}$	15	$4\frac{1}{8}$	15	$3\frac{15}{16}$
21	broke	..	......	21	$6\frac{7}{16}$	21	$6\frac{1}{2}$	21	$6\frac{3}{8}$	21	$6\frac{1}{2}$	21	$6\frac{5}{16}$	21	$6\frac{1}{2}$	21	broke	21	6
..	......	..	......	27	broke	27	broke	27	broke	27	broke	27	broke	27	broke	..	......	27	broke
..	......	..	......	..	......	..	......	..	......	..	......	..	......	..	......	..	......	..	......
$52\frac{1}{2}$		22		$76\frac{1}{2}$		$76\frac{1}{2}$		$76\frac{1}{2}$		$76\frac{1}{2}$		$76\frac{1}{2}$		$76\frac{1}{2}$		$52\frac{1}{2}$		$76\frac{1}{2}$	

six ingots, three out of each.

0.051	0.059	0.073	0.070	0.060	0.060	0.059	0.057	0.070	0.062
0.060	0.060	0.060	0.060	0.050	0.060	0.050	0.040	0.050	0.050
0.560	0.550	0.570	0.560	0.560	0.580	0.570	0.500	0.550	0.580
0.069	0.066	0.072	0.063	0.069	0.066	0.063	0.072	0.087	0.084
1.050	1.060	1.070	1.040	1.040	1.070	1.030	0.870	0.930	1.060
0.045	0.051	0.026	0.039	0.061	0.059	0.045	0.049	0.057	0.063
98.165	98.154	98.129	98.168	98.160	98.105	98.183	98.412	98.256	98.101

was 10 ft., and in each case the running head was up.

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without throwing any light on this very great difference in the fall required for rupture. This will be best reserved for cases to be presently described.

Those members who have read the classic work of Professor Henry Marion Howe, who confirmed observations made at the Clarence Works, will remember his description of the absorbing power of liquid steel in occluding gaseous matter, which latter was given off as the molten metal cooled. He naturally inferred that the uppermost portion of the ingot would contain the largest portion of the liberated gas which was imprisoned in spherical cells. When the ingot was rolled into a rail these cells were flattened but not entirely obliterated.

Trials were made by dividing each ingot into three parts, which were marked top, middle and bottom, and a rail was rolled from each. Six rails from each section were rolled and were exposed to the following test. A reference to Table No. 1 shows that the fractures took place as follows:

From the "Tops" at an average of 48.9 ft., "Middles" 64.5 ft., and the "Bottoms" 77 ft., and, further, that the analyses fail to connect these with any differences in chemical composition.

A committee appointed by the British Board of Trade has concluded a long inquiry, in which evidence of an exhaustive character was given. In it the data just quoted, besides much more of a highly important character, are to be found.

The changes in molecular structure, supplemented by microphotographic plates, are described at great length and with great ability by Professor Roberts Austen.

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PAPERS AND DISCUSSIONS.

Note.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

FILTRATION OF WATER FOR PUBLIC USE.

An Informal Discussion at the Annual Convention, July 3d and 5th, 1900.*

Subject for Discussion.

"The several Processes now used for the Removal of Objectionable Matter; their Comparative Sanitary Effect, Cost and Reliability."

By Messrs. George W. Fuller, Samuel Rideal, Henry Davey, J. N. Greene, Ad. Kemna, Walter Hunter and H. Alfred Roechling.

George W. Fuller, Assoc. M. Am. Soc. C. E.—For the engineer who has to consider water filtration problems in different parts of America, the speaker thinks there is no point more deeply impressed on his mind than that the waters from different sections of the country possess to a large degree a distinct individuality in reference to their purification. Having listened to the excellent *résumé* of this topic by Mr. Hering, the description of the Warsaw filters by Mr. Lindley, and the discussion on English practice by Mr. Deacon, it is thought that it would be of interest to look at the subject for a few moments from the standpoint of the applicability of different methods of purification to different types of water. Mr. Fuller.

One of the fundamental principles of water purification, as viewed

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* The discussion of this subject, for which no formal paper was presented, is continued from the August number of *Proceedings* in order that the views expressed may be brought before all members of the Society for further discussion.

Communications on this subject received prior to October 26th, 1900, will be printed in a later number of *Proceedings*, and subsequently the whole discussion will be published in *Transactions*.

Mr Fuller. from experience in America, is that the quality and the composition of the water to be filtered are factors of prime importance. This is particularly so with American surface waters, where there are wide ranges in character. In this discussion consideration is given only to surface waters, and not to ground-waters which may need treatment for the removal of iron. With the surface waters from different sections of the country, the most variable features, from the purification standpoint, are with reference to turbidity and color. By turbidity is meant the sand, silt, clay and those matters of an amorphous and organic nature which are contained in the water in suspension; and by color is meant the vegetable matter which is dissolved in the water, and which gives what is called by many a vegetable stain.

In the original application of water purification, improvement in the appearance of the water was, of course, the object sought. Within the last fifteen or twenty years the problem has changed, as is well known, and, fundamentally, the object now to be secured is the removal of those bacteria which are associated with the causation of disease. In looking at the problem from that point of view, it may be of interest to point out a difference which occurs between conditions in America and in Europe.

In Europe, particularly in England and in the western portion of the Continent, or, more accurately, with those filtered waters with which American engineers are more familiar, the speaker understands that it is generally true that if the water is filtered so as to eliminate the bacteria, the appearance of the water is satisfactory. That is to say, if the effluent is satisfactory from a hygienic standpoint, it is not necessary to give attention to the appearance of the filtered water. But in America the reverse of this would be true in numerous instances. In many places—not in the northeastern portion of the country, but in the South and Central West—the character of the waters is such that if the water after filtration is satisfactory in appearance, it is also substantially free from bacteria. This shows, in a general way, a difference, which perhaps is seldom appreciated, in the conditions in America and in Europe. The reason for this, of course, is that the clay particles found in the southern and western waters of America are much smaller in size than the bacteria. It is a fact that many of the clay particles in these waters are not more than 0.000011 in. in average diameter, or about one-tenth the size of the ordinary bacterium. Some of the clay particles are still smaller, and, without doubt, our estimates of their size are much limited by the present facilities for measurement under the microscope.

While a filtered water, of course, should primarily be as free of bacteria as is practicable, it appears to the speaker that the appearance of the water should also be satisfactory, in order to fulfill requirements as found in many cases. In this connection, it is to be borne in mind

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that many water consumers judge the character of a water by its appearance; and, regardless of the hygienic side of the question, do not look with especial favor upon a water which is either turbid or colored to a considerable degree. Public opinion in America appears to be undergoing a gradual but distinct change in this respect. Colored and turbid waters which seemed to be acceptable a few years ago are now complained of in many instances; and, in the opinion of the speaker, the development of the "spring water" trade and of house filters, is suggestive of conditions which water-works engineers must consider in the near future.

When turbid waters in America are to be purified for hygienic reasons, it seems to be the consensus of opinion that the purification works should yield an effluent which is also practically free from turbidity at all times. With waters containing much vegetable stain opinion varies widely. In fact, in America it would seem that the amount of permissible (dissolved) color in a first-class water is one of the most unsettled points at present, in connection with water supply and water purification. The permissible limit depends, of course, to a large degree, upon the point of view of the observer. Perhaps the most critical observers at present in America are the water consumers themselves, who judge the appearance of the water in bulk with a white background as they see it on their tables and in porcelain-lined bath tubs.

To decide, in a conservative and reasonable manner, upon the permissible amount of dissolved color in water for the future requirements in America is a task which is as difficult as it is desirable. So far as the speaker has been able to form a judgment upon this matter, he would be inclined to place the limit at 0.30 part of dissolved color by the platinum-cobalt standard. This amount of color is about half of that frequently seen in many waters in the eastern part of America, and about double the amount found in the southern and western waters after the removal of the suspended silt and clay.

Returning now to the character of the American waters, it may be said, in a general way, that there are three types, as viewed from the present standpoint of purification. There is, first, the water from those comparatively short rivers, and from lakes and ponds, which lie within the glacial drift formation, that is, the waters best known to us as those of New England and the northern Atlantic States. There is also another very distinct type of water which lies south of the glacial drift formation almost entirely, that is, the large rivers lying south of and including the Potomac, the Ohio, the Missouri, and extending from the Atlantic Ocean west to the Rocky Mountains. Between these types there is an intermediate class resembling in a measure the two; such waters as are found in the Delaware, the Susquehanna, the Allegheny, and rivers which lie along the dividing line

Mr. Fuller. between the drift formation and the section of country where the drift is absent.

To attempt to make specific comparisons of these types of water is a very difficult matter at the present time. In the first place, the amount of analytical evidence, with few exceptions, is very meager indeed, and especially with reference to results from samples which represent the normal and maximum conditions that the engineer must consider in the design of purification works. There is also another reason why these data are somewhat wanting in the significance they carry, and that is the lack of uniformity in the analytical methods used in obtaining the results. This latter point is becoming realized more and more clearly by engineers, and also by the analysts themselves. In passing, it may be of interest to state that an effort is being made to correct this state of affairs. At the last meeting of the American Public Health Association a section of Chemistry and Bacteriology was formed, and there was appointed under that section a Standing Committee to consider the question of Standard Uniform Methods of Water Analysis. Ultimately, it is hoped that some good may come of this.

Comparing with each other these general types of American surface waters in regard to the turbidity, or suspended matters which they contain, it may be said that those bodies of water lying wholly in the area of the glacial drift formation, such waters as that of the Merrimac, Connecticut, Hudson and Passaic Rivers, carry from about 5 to 15 parts per million of suspended matters as an annual average. This quantity is greatly exceeded at times of heavy floods, and in the case of the Merrimac River the amount of suspended matter has been known to exceed 1 000 parts per million. The conditions of the spring freshet in this instance, however, were abnormal. With regard to the character of the turbidity in this type of water, it may be stated that, comparatively speaking, it is caused by fine silt, and not by clay. Accordingly, it is a type of water which is not very troublesome in its purification, as the silt can be removed quite readily by subsidence.

The waters of the second class, those of the South and West, contain very large amounts of suspended matter. The annual average amounts in the Ohio River water have been found to be 230 and 350 parts per million at Cincinnati and Louisville, respectively. In the case of the Mississippi River water there are records showing the annual average amount of suspended matter at St. Louis to be about 1 000 parts per million, and about 560 parts at New Orleans. These records cover information obtained at different times during the past fifty years, and are by no means strictly comparable with each other. They are sufficient, however, to show that this general type of water contains roughly from twenty-five to fifty times as much suspended matter, on an average, as do the waters of the northern Atlantic sea-

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board in America, and also the English river waters as the latter are known to American engineers. From a practical purification standpoint the comparative difficulty in handling the very turbid river waters of the South and West is by no means adequately shown by the annual average amounts of suspended matter. There are several reasons for this. In the first place, the flood periods continue uninterruptedly for many weeks, and, in some instances, extend over several months, during which time the suspended matters vary very rapidly and continue normally in excess of the annual average, reaching at times more than 5 000 parts per million. Another feature of great importance in explaining the difficulty in purifying these very turbid waters is the fact that a considerable proportion, say about one-fourth, of the suspended matters consist of minute clay particles. The sub-microscopic nature of these particles has already been referred to by the speaker, and it may be further added that it is practically impossible to remove them by subsidence.

The third, or intermediate, class of water, such as found in the Delaware, Susquehanna and Allegheny, etc., contains suspended matters ranging apparently from about 25 to 75 parts per million, on an average. In duration of flood periods, proportion of clay particles and in the size of clay particles, this class of water stands intermediate between the two previously described. The evidence, however, shows that in some instances there are decided complications from coal dust and mine drainage.

With regard to the amount of dissolved color or vegetable stain contained in these general types of water, it may be said that many, but by no means all, waters of the first class contain more color than is considered by some to be satisfactory. To this class of waters of the glacial drift area there must be added swamp waters from all sections of the country. No attempt will be made to show in detail the general evidence as to the color of this type of water, partly because of lack of available comparable records, and partly because of the unsettled condition of the problem of what amount of color is permissible in a first-class public water supply.

The dissolved color in the waters of the second and third types is not a factor of practical significance, so far as the speaker has been able to learn. Undoubtedly, organic matter capable of producing a vegetable stain reaches these turbid waters, but it seems to be removed in the streams and settling basins. Apparently, it becomes united to the silt and clay particles (hydrosilicate of aluminum) and settles to the bottom with them. In a measure, this may be called filtration of silt and clay through water.

From this account of the conditions met with in America, it will be seen that the method of purification to be adopted in any instance must be adjusted to the requirements of the water under considera-

Mr. Fuller. tion. Further, the character of many surface waters in America is such that, in the design of purification works which shall successfully meet the requirements of the future, careful attention must be given, not only to the question of bacterial removal, but also to the decolorization and clarification of the water.

Of the methods of purification now considered in America, there are two important ones, as has been very clearly shown by Mr. Hering, who has described and compared their leading characteristics. The nomenclature used in this line of work in America is in quite a transitional and unsettled state. The term "filtration of water" was satisfactory so long as it was applied to waters which were not excessively colored or turbid. Since the subject has grown and included the consideration of the more complicated types of water, the term "purification of water" is considered by many to be more logical and comprehensive. For many waters, filtration by itself is inadequate, and there are required in connection therewith plain subsidence, coagulation, and supplementary subsidence. In some places the expression "method of filtration" has been replaced by "method" or "systems of purification." With regard to the two methods of filtration proper, they are variously spoken of as sand, or English, or slow filters, and as mechanical, or American, or rapid filters, respectively. Upon comparing the two methods of filtration when each is operating at a high degree of efficiency, it is found that there is a long series of differential features, of which the most important is the physical condition of the water as it enters the sand layer. To many it seems desirable to avoid a nomenclature which gives undue prominence to one superficial feature, and to use a name which implies a series of conditions requisite for first-class work. By these engineers the two methods are called English and American filters, respectively, from the countries where they are first developed.

Water purification on a practical scale in America is in its infancy. Ten years ago its application was almost nominal. During the past decade, however, considerable progress has been made in the small cities and towns. At present it may be said, in general terms, that there are about 20 English sand filters in service in America, having an area of about 17 acres, and yielding about 25 000 000 galls. of water as a daily average. There are also in service about 160 American, or mechanical, filter plants, having a nominal capacity of about 250 000-000 galls. daily, but actually supplying a consumption of only about half this quantity.

With few exceptions, these purification plants by both methods are very small, and there is comparatively little information available, showing continuously in detail the efficiency and the cost of operation. Under these circumstances, American engineers are obliged to base their detailed knowledge of water purification, in a large measure,

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upon the results of European experience and of the careful investigations made on an experimental scale at Lawrence, Providence, Louisville, Pittsburg and Cincinnati. The European experience, in connection with the purification of waters comparable to those now filtered abroad, has been carefully followed in America for many years, beginning with the classical report made by the late James P. Kirkwood, M. Am. Soc. C. E., for the City of St. Louis. For the purification of the more difficult types of water, due to their excessive color or turbidity, dependence is now placed on the laws of purification as deduced by the special studies in the cities just named. Upon the more important points it is considered that this evidence is substantially correct for the types of water actually studied, and it is now being used as a guide in the design and construction of purification works for a number of the larger American cities.

Concerning the relative merits of the two leading methods of purification, the experience of the speaker has led him to the opinion that English sand filters, as a rule, are most satisfactory in point of efficiency and economy for those waters for which they are strictly applicable. Such waters may be defined as the non-clay-bearing waters, which are only slightly or moderately discolored by vegetable stain, and which are found in the first type of waters mentioned in this discussion. Although it is well known that these filters have decided limitations in the successful treatment of very colored and very turbid waters, it is a difficult matter at present to define satisfactorily the dividing line between those waters for which this method of purification is applicable or non-applicable. There are some cases in which this method is strictly applicable for the local water where it is probable that its adoption would be inadvisable on the ground of cost, owing to the area which it requires, thus necessitating an isolated location and an extra pumping of the water. Notwithstanding the fact that English sand filters are applicable for a far smaller proportion of the American water supplies than was generally considered to be the case a few years ago, it is the opinion of the speaker that they have a large field of usefulness in America, and that they will be adopted in many places within the next few years.

Referring to the construction and operation of English sand filters in America, it may be fairly said that the recently completed purification works at Albany, N. Y., designed by Allen Hazen, M. Am. Soc. C. E., and described in a recent paper* before the Society, may be taken as representative of the best current knowledge in this line, based both on European experience and American investigations. These filters differ much from the older filters of Europe, but do not differ very materially upon the more vital points, when compared with the best modern filters abroad. Nevertheless, they have an individuality

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* *Transactions*, Am. Soc. C. E., Vol. xliii, page 244.

Mr. Fuller. of their own. Among the more interesting and important features of the Albany filters, from the standpoint of efficiency and economy, are the arrangement of the floor with the thin layers of gravel to support the sand, and the means taken to prevent the passage of water between the walls and the sand.

The recent estimates made for English sand filters at a number of American cities are on the basis of an average capacity of 3 000 000 galls. (U. S.) per acre daily. In view of the fact that the maximum consumption in some places ranges from 25 to 50% above the average, during very hot and very cold weather, the rate would at times reach between 4 000 000 and 5 000 000 galls. per acre daily, even with moderately large distributing and compensating reservoirs. From present evidence this seems reasonably safe for very short periods, unless the raw water should be excessively polluted. In fact, it appeared from experimental evidence obtained several years ago at Lawrence and elsewhere, that, with some kinds of water, rates of 5 000 000 and even 7 500 000 galls. per acre could be safely used. More recently, however, the very careful studies made at Lawrence, with reference to the passage of *Bacillus Coli Communis*, the leading intestinal bacterium, indicate that these rates are too high for such waters as that of the Merrimac River. In the event that rates of filtration have to be increased materially, to meet unusual conditions of consumption, experience indicates that the changes should be made gradually and not suddenly. In fact, proper regulation of the rate of filtration is now universally recognized as an essential feature of successful filtration; and the introduction of devices to secure this end show one of the most marked improvements in the new over the older filters.

There is some difference of opinion in America concerning the conditions under which covers should be provided for English sand filters. A few years ago it was thought that this could be settled by use of the mean January temperature, on the basis that covers would be required where this temperature was at or below the freezing point. More detailed studies of temperature conditions, however, show that every few years there are exceptionally cold winters during which there are so many days in succession when it would not be practicable to scrape open filters, that the foregoing rule seems to be questionable. According to the opinion of many engineers, experience will ultimately show that covers are an advantage at nearly all points on and north of the Potomac and Ohio Rivers. If this should prove true, it would necessitate covers in nearly all the American territory where English sand filters now appear to be applicable. With regard to the effect which covers produce upon the bacterial efficiency of the filter, in connection with vegetable growths, etc., this is a point upon which there is very little or no evidence in America.

With regard to the American or mechanical filters, it is well known that they are proprietory devices of comparatively recent origin. The more important patents, however, will expire shortly. Prior to 1885 these filters were used exclusively in the treatment of water for industrial purposes for the removal of vegetable stain and turbidity. Since that date they have been introduced for the purification of many public water supplies, and during the last few years progress has been very rapid. For the most part they have been installed for small works, not so much because they were necessarily the most applicable process for each water, but rather perhaps on account of the filter companies guaranteeing certain results with devices of fairly low first cost. Mr. Fuller.

Up to 1895 very little was known of the hygienic efficiency or cost of operation of these filters. Naturally, they were not looked upon with favor by the great majority of engineers. During the last five years there has been a great increase in our knowledge of the leading features connected with these filters. This is particularly so in the detailed knowledge of coagulating processes, which are such a vital matter in this type of filter. Without coagulation one can expect from them no hygienic efficiency. As already stated, the proper degree of coagulation of the water as it enters the sand layer is the keynote to their successful work. When this is satisfactory, such factors as rate of filtration, size of sand grain, thickness of sand layer and detailed method of cleaning the sand layer, appear, within reasonable limits, to drop into comparative insignificance. At one time it was quite universally feared that the use of such coagulants as sulphate of alumina might result prejudicially to the health of those using water purified in this manner. As a result of most careful studies upon this point, it may now be stated that when the coagulant is applied in proper quantities in the presence of proper quantities of alkaline constituents of the water, there need be no fear of undecomposed chemical in the effluent. With this process it is imperative that the supervision should be such that at no time should the inadmissible result be met of applying more coagulant than can be completely decomposed. In this decomposition there is a conversion of the carbonates of lime and magnesia into the sulphates of these bases, with the liberation of a corresponding quantity of carbonic acid. The alumina itself is, of course, removed as a flocculent precipitate.

If the merits of filters of this type were to be judged from the general knowledge as to their efficiency, as now obtained in practice in the majority of cases, the indications are that it would not receive a rating of the highest grade. This seems to be due, in part, to a lack of the necessary skilled supervision at small plants, and, in part, to a desire to avoid the expense of applying a sufficient quantity of coagulant. From the results of extended investigations upon the subject, however, it is considered that sufficient knowledge is available

Mr. Fuller. to design and operate by this method plants which will give first-class results, when judged practically from the highest plane of excellence. From the added knowledge of tests of short duration upon recently constructed plants in practice, it is felt by the speaker that the laws of this process, so far as they have been formulated, are substantially sound and accurate.

Concerning the applicability of this method of purification, it is the judgment of the speaker that, for the non-clay-bearing waters, which are low in amount of dissolved color, it is, as a rule, less suitable than English sand filters. This is based on the present general evidence that for this type of water the English filters can give a thoroughly satisfactory effluent, and at a total cost equal to or slightly less than that of American filters; that the use of coagulants is to be avoided where not imperative; and that the use of coagulants for these waters is especially undesirable and exacting in the control of their application, due to their low alkalinity. There are, of course, exceptions to this general rule, such, for instance, as cases where the compact form of the American filters would permit of a location where extra pumping would be avoided, and where this could not be done with English filters.

The especial field of usefulness for the American filter is in connection with the purification of those waters which are either so highly colored, or so highly charged with sub-microscopic clay particles, that it is impossible to obtain satisfactory results without the use of coagulants. With waters which require a coagulant, either constantly or for the great majority of the time, the present evidence shows that, as a rule, the American system of purification is the better. For very turbid waters this system consists of plain subsidence, coagulation and supplementary subsidence, and mechanical filters. For such waters the use of English sand filters would increase the total cost somewhat; they would give normally no higher grade of purification; they would be more difficult to operate; and, for the latter reason, there would be a tendency for them to yield a less satisfactory effluent at times when the river water would be most variable in character.

In explanation of the point that, with English filters, purification plants for very turbid waters would be more difficult to operate, it may be said that the great rapidity with which the character of the water changes makes it very difficult, and in a measure impossible, to apply at all times just the proper quantity of coagulant at the inlet to the coagulating basin. Obviously, this would be kept as low as consistent with good efficiency, for the sake of economy. If it should be found that the application of coagulant was too small, it is possible with American filters to correct this by adding more coagulant as the water reaches the filters, thus maintaining the efficiency of the plant. With English filters this is not possible, because, if the coagulant were applied at the outlet of the coagulating basin, it would clog the surface of the sand very quickly, and put the entire plant out of service for some little time. From a practical standpoint, the speaker attaches great importance to this feature, which was repeatedly noted during the investigations at Cincinnati. Mr. Fuller.

There has as yet been very little experience in the purification of waters containing large amounts of dissolved color. Judging from experience with the recently completed works at Norfolk, Va., it appears that the American method with mechanical filters is the better, for reasons similar to those stated for the clay-bearing waters.

Concerning the purification of those intermediate types of water, which for short periods are moderately colored or turbid, there are not sufficient data to draw any well-defined lines. A careful study of local conditions, with reference to the characteristics of the two methods of purification, can alone settle the matter properly for the present.

Samuel Rideal, D. Sc.*—The remarks on the American practice with mechanical filters has greatly interested the speaker. Speaking as an English chemist and bacteriologist, he thought that the lesson to be learned from this discussion was that English engineers should give these mechanical filters a trial in this country, parallel to the trials that American engineers were giving to the English method of sand filtration. Mr. Fuller's remarks seem to show that there is a future for mechanical filters in England, where recent practice has been to do away with the sand-filtered water supplies from rivers, and to go to the mountain and upland surface waters, many of which, containing vegetable coloring matter, would seem to be very amenable to this mechanical filtration. These waters frequently give rise to plumbism. With a mechanical filter using alum (and lime, if the water is not sufficiently hard from carbonate of lime), the coagulant would correct that evil; so that with mechanical filtration, using alum with or without lime, we should affect removal of the vegetable coloring matter and prevent plumbism at the same time. That our method of sand filtration seems generally to give a better bacterial purity than the mechanical filters, may be due to the fact that the latter have been worked at a much greater rate, and perhaps with the minimum quantity of coagulant, without due regard to the reduction of bacteria; a difference that doubtless could be removed. Dr. Rideal.

Neither method of filtration can, however, be regarded as a satisfactory means for preventing the appearance of pathogenic germs in water. No matter how small the fraction of the organisms left, there might be among them some which might be injurious to health. Therefore, although either sand filtration or mechanical filtration is a very good line of defence, it is not the only line of defence one should rely upon.

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* London.

Dr. Rideal.

The speaker believes that the question of sterilizing water will soon become prominent, and that the removal of pathogenic organisms can only be effected satisfactorily and economically by heat sterilizing. He used the term "heat sterilizing" (a somewhat misleading phrase) purposely, because he wished to accentuate before a body of engineers that it is not a question of heat sterilization at all, but a temperature condition. The organisms are killed when they reach a certain temperature, and a maintenance of this condition does not necessarily involve the expenditure of any energy.

The problem of bringing a body of water to a high temperature, and keeping it at that temperature sufficiently long to ensure the death of the organisms present, is one which he believes would be worth while for engineers in this country and in the States to pay special attention to. The cost of bringing very small quantities of water—perhaps two or three pints per head of the population, instead of the 65 or 75 gallons—to a temperature which will ensure the killing off of the pathogenic organisms, cannot be very large. By a proper system of incoming and outcoming of the water, and possibly by a vacuum jacket such as is used for maintaining a very low temperature, the expenditure of the heat or energy, either gas or electric heating, which would be required for bringing about such local sterilization of water for potable purposes, would be very small indeed. Probably in the States as well as in this country legislation could be brought to bear in the same way that we now have by-laws for limiting the quantity of waste in flushing closets. In this way it would be possible for the municipalities to supply to every consumer a machine for producing sufficient sterilized water for potable purposes, while leaving the supplies and mains in their present condition.

Mr. Davey.

Henry Davey,* M. Inst. C. E.—The speaker thinks that a high tribute is due to Mr. Hering for his discussion, in which the case is stated very clearly, and in which opinions are expressed which seem perfectly in accordance with the facts of practice. On this question, and referring only to the English practice, or what has been termed the sand filter, the speaker, who for many years has had charge of very large filter beds dealing with large quantities of very impure river water which it is necessary to filter and bring into a proper state for domestic use, has very little to say, because the general principles have been so thoroughly stated that he could only repeat what has been already said, or go into minute questions of detail which would not be profitable.

He would, however, like to emphasize what has already been said. The question of sedimentation is a highly important one. If storage reservoirs can be made sufficiently capacious, the quality of the water may be so improved that the work on the filters is reduced. In the

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* Engineer, Birmingham, England, Water-Works.

Mr. Davey. sand filter, as has been pointed out already, it is only the thin layer of the surface that does the work, and the object is to maintain that thin stratum in a quiescent state in order that the bacteriological effects may properly take place. The rate of filtration, then, is an important point, because time must be given for these bacteriological operations. Four inches per hour has been named, and that, according to the speaker's experience, is good practice in England; but, as Mr. Deacon has intimated, the longer the filter works, the less will be the rate. If an average of 4 ins. is taken, it may be too rapid to begin with. We know that when the water is put on the filter immediately after the filter has been cleansed, that there is very little effect—the water goes through. The filter should be worked for the first two or three days at an exceedingly low rate in order to produce the film that is necessary without letting many bacteria go through. When the filters are newly made they should be worked very slowly indeed to get the best results. Much depends on the class of water, but, from the speaker's experience, 4 ins. per hour should be the maximum with waters that are high in bacteria.

Although a thin layer of sand is all that is necessary to maintain the surface film, yet a considerable thickness is desirable, for the reasons which have been mentioned by Mr. Deacon. The speaker has found that in a section of the filter bed having a depth of sand of say 4 ft., there are streaks of pollution through the sand, showing that if that had been very much thinner much polluted matter would have gone through. He thinks it is a safe thing to have a great depth of sand, but, as has been already pointed out, it should be sand and not pebbles and gravel, which are only useful as a support. An important point which has given the speaker considerable trouble is that, unless the inlet to the filter is properly constructed, the current of water around it disturbs the sand, and the water at once finds its way down through without the surface film being formed. It is not necessary to go into the actual construction, but merely to mention that the distribution of the water over the filter and on the filter, in such a way that the surface is not disturbed, is an important point to be taken into consideration.

Mr. Greene. J. N. Greene, M. Am. Soc. C. E.—The speaker would like to ask some of the learned gentlemen who have discussed these questions, and who have had experience in filtration, to explain how to eliminate from the filtered water, after it has gone through the filter, all the filthy things, such as the drainings from cesspools, stables, dye houses, tanneries and everything that borders the streams which flow into the river; how can all those impurities, which are held in solution, be eliminated, and a good water be secured by filtering?

The real secret of this evil of consumption of foul water lies often, and, indeed, in most cases, in the short-sighted, make-shift way in

Mr. Greene. which communities treat this, one of the most important subjects connected with their life and health. In numerous instances, all over this and other countries, large cities and small communities, upon this "good-enough-for-the-present" plan of doing things, have expended large sums upon impure water improvement, knowing it to be so at the start, and growing worse every year; and, even with such experiences, go on and enlarge the same, at great outlays of money, which they do only to increase an existing evil, instead of putting the knife to the root and expending their money for new plant to secure pure, or approximately pure, water. Philadelphia, Pa., and Bangor, Me., are striking examples of this class. In short, the speaker does not believe it is practicable or possible to obtain pure water by filtering water which is loaded with impurities held in solution when the filtering process is begun.

The surest way to get pure water is to go further and spend more money and get water that is pure and fit to use, without the artificial and never-satisfactory process of filtering.

Dr. Kemna. DR. AD. KEMNA (Antwerp, Belgium).—It is apparently easy to point out many shortcomings in the introductory discussion, and practically this is what has been attempted by the various speakers. But on closer examination it appears that all that has been said may be found in a very concise form in Mr. Hering's discussion, the interesting discussions being but instances of the general principles laid down as a basis.

There is, however, one important point which it is necessary to emphasize. The action of sand filtration is essentially a biological one. The mechanical action of straining is obvious; but, as microbes are much smaller than the interstices between the grains, this action alone does not account for their retention, and it is absolutely inadequate for the reduction of the dissolved organic matter. Various theories have been proposed; the one which considers reduction as a fermentation is consistent with the greatest number and the greatest variety of facts.

So, for example, an apparent contradiction can be easily explained. Animal pollution is easily reduced by filtration, while we have it on the authority of Mr. Fuller that vegetable color is extremely hard to remove. Now we know from our school chemistry that vegetable organic compounds are much more stable than animal nitrogenous contamination; the filter masters the one and fails with the other. Besides, microbes do not act on all substances; in racemic acid the tartrate will be destroyed and the right remains unaltered; similar cases are likely to occur with the mixture we call organic matter in water.

Negative proofs can be given of that biological action. In moderate climates, the bacterial efficiency of sand filtration is over 99%; but in colder climates, like Warsaw and Odessa, only 96% is reached, and, according to Simin (Moscow), the reduction is as low as 60 per cent.

Dr. Kemna.

There was a spell of sharp frost over Western Europe in December, 1899. The cold had not set in three days before the filters of Antwerp gave insufficient bacterial and chemical purification. The size of a pin's head of the slimy upper layer gives in the field of the microscope generally over 200 living organisms, chiefly diatoms; during the cold there were 4 or 5, and it seems reasonable to admit that their vital activity also is greatly diminished. A chemical process (iron and marble) was applied with good results to insure the quality of the supply.

Another proof is the interesting fact that at Louisville, according to Mr. Fuller, ordinary sand filtration does not work; the high turbidity of the Ohio water shuts out the light, which is essential to the development of diatoms.

The sand filter has been, and is still, in many places, a very simple thing; it is a heap of sand; water is poured on the top and extracted from underneath; it is worked by a foreman, who knows, of course, how much water he pumps on the filters, but he cannot always tell how much each particular filter is doing, its speed, etc.; generally the filters are left to settle that between themselves. This is the acme of simplicity.

But now compare with what has been said up to the present time. At the intake end, Mr. Lindley wants a very elaborate arrangement for subsidence, to be worked differently according to meteorological data. In summer the water is made to travel downward; in winter it is to take the reverse course. The admission to the filters is regulated by automatic processes so as to keep a constant level above the sand. The filter itself, as described in 1889* presented many special features, namely, a series of layers of gravel systematically arranged. The water is not allowed to leave the filter without having to pass a special chamber, with automatic machinery to regulate its flow. But its troubles are not over yet, for now comes in Dr. Rideal, who says: "Filtration does very well; it takes out 99.9 and a series of 9's of microbes, and I want to kill by heat the last one." All these various processes added together make up a long list of complicated appliances.

It has been said that facts are the only things considered by engineers. But facts are nothing by themselves and they get a bearing only in conjunction with a theory to explain them; if it is contended that there is no theory, that means only that there is no avowed theory and that we are led by an unconscious one. Can there be any doubt that an outspoken theory, which can be discussed, is to be preferred? The very common belief that theory is of no practical avail and is at the best an intellectual luxury is utterly wrong; it is an inquiry as to causes of phenomena and the reasons for things and is therefore an

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* Congrés pour l'Utilisation des Eaux Fluviales, à Paris.

Dr. Kemna. absolute necessity. No better example can be adduced than sand filtration itself, which made no progress during fifty years, and was rapidly modified and perfected as soon as the biological theory gave the right explanation. It will pay to examine by the light of our theoretical knowledge, as far as possible, the various complications which have been proposed in the ordinary sand filter. But at the same time we must keep in mind that there are practical limits.

Taking up again the course of the water, we meet at first sedimentation, relied upon in England for improving the quality. Direct oxygenation is the explanation which probably is in the minds of most engineers; but experimental proof of this action could not be given. Mr. Fuller has suggested another cause—the subtraction of dissolved organic matter by the suspended clay. Then there is vegetable life favored by light, which also does a good deal. But it is still an open question whether the amount of preliminary purification is worth the money invested in large reservoirs.

When the water is kept in constant motion, Mr. Lindley's scheme seems the best to ensure the utilization of the full volume of the reservoir for decantation. The walls and partitions necessary to make the different channels are a small extra cost when the reservoir is covered, as it must be under a climate like that of Warsaw. But when ordinary open reservoirs are used, the surplus expenditure becomes comparatively large. It can be avoided altogether, however, by subdividing the reservoir into separate sections, successively drawn upon, and in which there will be no flow at all; many observations seem to show that there is a better settling with a few hours' complete rest, than with a long run even at a very slow speed. This very simple theoretical consideration enables us to consider the complications of the intake, not as an absolute advantage in all cases.

A great deal of simplification has been done by Mr. Lindley himself as to the gravel. The only part the gravel has to play is to give a support to the sand and an exit for the water; and as soon as this is done efficiently, nothing more is wanted.

The thickness of the sand is a much-discussed question; the small size of the grain is all-important for the mechanical action of straining; the thickness of the bed is all-important with the physical theory of surface action, very popular some decades ago, when chemistry told that dissolved matter was abstracted from the water. But it is an undisputed fact that quartz has only a very limited power of adhesion, quite unlike that which is so marked with aluminum compounds. In the light of the biological theory, the sand is something like the gravel—a support to the superficial living layer. The well-ascertained fact that thick filters give an effluent of more constant bacteriological composition has received a simple mechanical explanation from Allen Hazen, M. Am. Soc. C. E.; if the superficial layer is broken in some places, a thick bed of sand allows of only a small direct flow, and contamination is kept down to a minimum. Dr. Kemna.

As the reduction of dissolved organic matter is a fermentation, some time must be allowed for it; the retention of the microbes is a sort of compromise between the erosive mechanical action of running water and the stickiness of the stuff coating the sand grains; for these two reasons the rate of filtration must be kept within certain limits. The 4 ins. per hour, or about 2.5 m. per day, is the limit fixed by the German Imperial Health Office; it is a limit, and, as the engineer of Birmingham has very well pointed out, that speed cannot always be given. The pace of a man walking is, say, 1 m., but that cannot be expected from a child. When a filter has just been scraped it is in its infancy and must be worked very gently at first. As soon as the filtering layer has formed, the speed may be increased, and, according to experience at Antwerp, may be much more than the 4 ins. per hour and still give good results.

The suggestion of Dr. Rideal to sterilize the water is based on the fact that some epidemic diseases are caused by water-borne microbes. It is obvious that absolute security can only be obtained by complete sterilization, but the practice of fifty years' filtration proves that the risk of contamination is an exceedingly small one. A heating apparatus for thousands of cubic meters means a large expense; a special canalization for a few liters of water a day is another big item. It is a question whether that very small increase of security is worth the extra expense, the more so as the temperature of 70° Cent., mentioned by Dr. Rideal, will certainly not kill all the spores, some of which are very resistant.

The discussion has wavered between English and American filters. In both cases sand is applied, but that is the only point they have in common. In both cases this point is unimportant, the sand being only a support—in the ordinary filter a support to a layer of algæ and clay in which biological actions are prominent—in the mechanical filter, merely for straining out the coagulum. Ordinary sand filtration is not at all an artificial process. We cannot order life to multiply, and the microbes and algæ to work in a special way; we are completely at their mercy. In the mechanical filter a chemical compound of known composition and predetermined reactions is used which can be adequately dosed. The comparison between the two processes is really an antithetic one.

It is useless to emphasize the necessity of purifying all superficial waters when used for distribution. It is only a question of cost, depending, of course, on the amount of water to be treated; so that the possibility of bettering a supply is intimately connected with the stoppage of leaks and wasteful use. This appears to be very large in England and absolutely enormous in America. It causes large expen-

Dr. Kemna. diture to provide water, the tenth part of which only is really used. It also increases the amount of sewage, making here again purification more costly, and contaminating the water-course, sometimes the very river from which the supply is derived. Generally, people are shrewd enough not to pump the same water over and over again, but send it down the river to the town below. In the first case, the course of the water is a circulus of life; in the second case, it is a spiral.

Referring to the remarks of Mr. Walter Hunter, the speaker feels bound to say that the abandonment of bacteriological analyses for the water-supply of six million of people is a step in the wrong direction.

Answering Mr. Greene, it must be admitted that pollution cannot be kept out, and must therefore be dealt with. This the filter does, and the fact should be emphasized, that sand filtration is not an artificial or a theoretical process, that it is a natural process, especially because that process is exactly like what goes on in the purification of springs, which invalidates the sentimental argument against purified river water. A clear, beautiful, wholesome spring is something which comes out of the ground; but before coming out it was in; and before being in it had to come in from above as rain water through the air. The first stage of entrance, viz., the percolation through the upper layers of soil is a stage of enormous pollution, much greater than that of any stream. But lower down all is taken out by the natural agencies of the soil and by a series of very complicated chemical, physical and bacterial processes, exactly the same as in the surface layer of a sand filter. Engineers and scientists who have charge of a sand filter cannot claim that they do the work; it is the filter which does it for them, and does it very well.

Mr. Hunter. WALTER HUNTER,* M. Inst. C. E.—The speaker agrees with Mr. Davey and other speakers as to the desirability of sedimentation before filtration, as no doubt it eases the working of the filters, but wishes at present to deal especially with Dr. Rideal's remark, to the effect that it is necessary to take the last odd microbe out of the water. He recollects very well being told by Mr. Hawksley, whose name is so well known in the water world, that when he was at the meeting of the British Association at Bristol two years ago, there was a learned scientist there of the same profession as the learned doctor himself, who stated that he had put his children on sterilized food and water and they immediately began to droop. He found it was absolutely necessary to return to ordinary food and ordinary water in order that they might thrive. That is a practical illustration. The speaker thinks we owe an immense deal to the chemist and bacteriologist, who set us up an ideal to which we could strive to attain; but still he believes they sometimes go beyond what it is possible to attain in practice, and also beyond that which is really desirable. He has noticed that sometimes

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* Engineering Director, Grand Junction Water-Works Company of London.

Mr Hunter.

a sample of water has been termed inferior in quality, because it happened to have just double the quantity of certain chemical matters contained in another sample. Take organic carbon, for instance. One sample had 0.162 in 100 000 parts, and another sample 0.309, the difference being 0.147 in 100 000 parts, or $\frac{1}{680\,272}$. Again, organic nitrogen in one sample was 0.028 in 100 000 parts, and in another 0.033, a difference of 0.005 in 100 000 parts, or $\frac{1}{20\,000\,000}$. These are figures one cannot easily grasp, and are really infinitesimal, both samples being equally good for all practical purposes.

After all, the great testimony as to the quality of any water is found in the statistics in regard to the health of the community supplied. The admirable way in which the water supply of London is conducted, for instance, can be so shown. When the death rate in the Metropolis is, as it was a week or two ago, something between 12 and 13 per thousand, and when the average for the year continues from year to year to be something between 17 and 19, and when, too, the very small amount of enteric fever which we have in this enormous city is noticed, the inference that the filtration of the water is carried out in a very admirable way, and that the community has no need to fear in regard to the quality of that water, seems fully justified. The Thames has been wonderfully improved by the action of the Thames Conservancy during the past few years. The raw water taken from the river is at least 33% better than it was. We are able to deal with it absolutely well by filtration, taking out something like from 98 to 99%, or 99.999% of the microbes, and the chemical analyses, as made by Sir William Crookes and Professor Dewar, and also by the government analyst, Doctor Thorpe, are most satisfactory. The speaker desires to add that Doctor Thorpe, the new chemical examiner for London, has dropped the system of microbial examination which was adopted by the late Sir Edward Franklin, and confines his attention to chemical analysis.

Mr. Roechling.

H. ALFRED ROECHLING, M. Inst. C. E. (by letter).—The writer is very sorry not to have had the pleasure of joining in the oral discussion, but urgent unforeseen business had prevented him from doing so. He is glad, however, to make a few written observations, as he is of opinion that the exchange of views between brother engineers in different countries is very desirable and tends in the end to break down that barrier of apparent indifference which at times seems to exist.

He will confine his remarks to a point in sand filtration, which is frequently overlooked.

When Simpson first introduced sand filtration at the Chelsea Works on a large scale, about the year 1839, he had no idea in what manner the purification of water was brought about in this process; he imitated Nature, and, as Nature's own processes are generally simplicity and perfection, he succeeded. Since then this process has become popular in all countries, and its application has extended from year to

Mr. Roechling. year, but its merits were only instinctively guessed and were not exposed and explained scientifically until within the last 10 or 15 years, when, chiefly through the means supplied by Koch, it had become possible to ascertain the organized matter in water, *i. e.*, the germs, microbes, micro-organisms, or whatever name we may give these minute beings, which belong to the vegetable kingdom.

The results then obtained clearly proved that the process of purification in sand filtration was chiefly brought about by physical or mechanical agencies, *i. e.*, the suspended matters, both organized and anorganized (living and dead) were removed, but the chemical composition of the water was but little affected.

How did this take place?

The slimy skin, which formed sooner or later on the surface of every sand filter, when surface-derived waters were being filtered, acted as a very fine strainer in catching and retaining the suspended matters in the water. By degrees this skin became so exceedingly retentive that it would not even allow the liquid to pass through, and then the filter had to be cleaned.

But if there was an almost impermeable layer gradually forming on the sand surface, how was the air to pass through, without which the micro-organic life could not carry on its work in the pores of the sand, gradually splitting up organic matters and changing them into mineral substances? And even if the process of mineralizing organic matters were not entirely due to biological agencies, it was pretty well established that in the absence of oxygen these changes soon came to a standstill.

When it is remembered that sand filters are now being filled from below, and that every care is taken to drive out the air contained in the mass of the sand; when it is further kept in mind that afterward an impermeable skin is gradually formed on the surface, it is not surprising to find the results previously stated, viz., the removal from the water of all suspended matters, but no great improvement in the chemical composition of the water.

The writer had been asked how he explained a slight chemical improvement which was noticeable with most waters, and he had stated that these small chemical changes went on until the oxygen contained in the sand and water was used up.

Totally different to the sand filtration of drinking water was the filtration of sewage or any other impure liquid through land, which process the writer had named the natural self-purification of sewage. Here it was of the utmost importance to prevent a crust forming on the surface of the land, so as to admit plenty of air to the micro-organic life in the soil, which carried on the benevolent work of mineralizing organic waste matters.

The writer has not time to go into the very interesting difference

Mr. Roechling.

between water and sewage filters, and will only point out that the conditions of work in them are reversed, hence the results are reversed also. In the filtrate from sand filters there are but few germs and no chemical improvement; in the effluent from sewage filters there are millions of germs and a decided chemical improvement.

In conclusion, the writer is of opinion that the raw material for a public supply for drinking purposes should be chemically and otherwise as free from objection as possible, so as to reduce the difficulties and the costs of purification, because it is a lengthy and expensive process to use first a filter constructed on the same principles as a sewage filter and afterward a water filter, as we now understand them.

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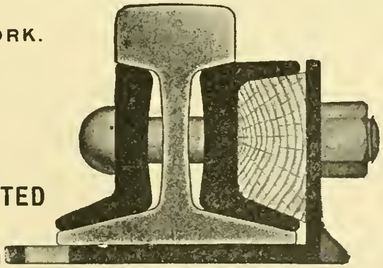

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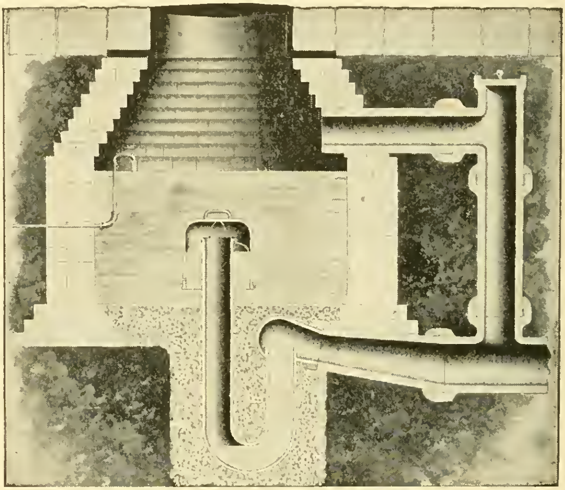

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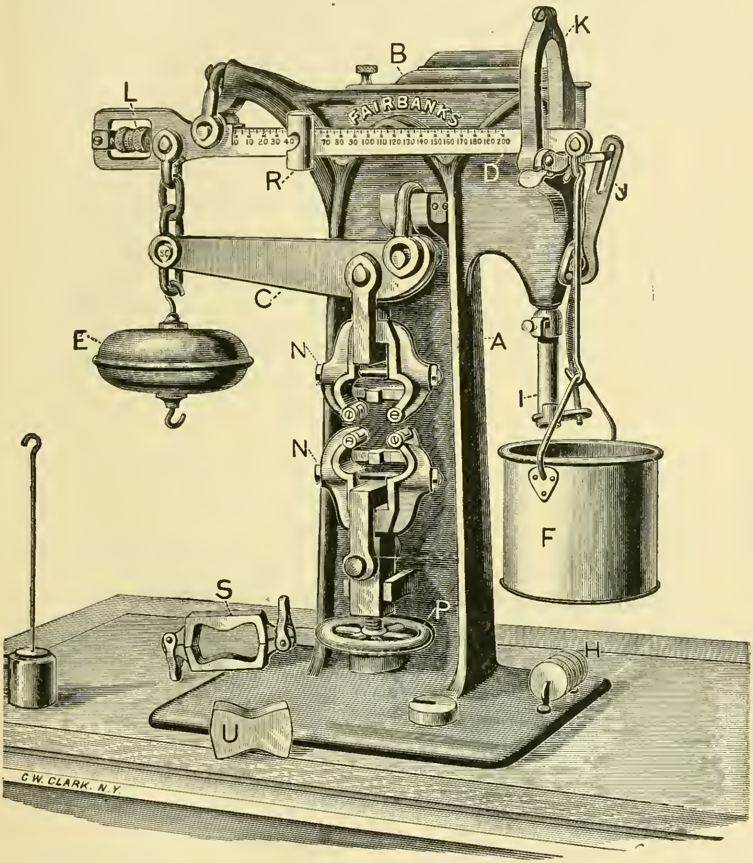

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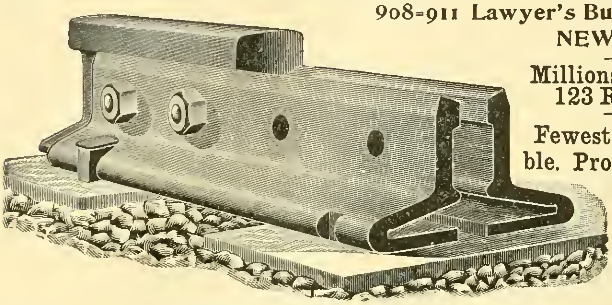

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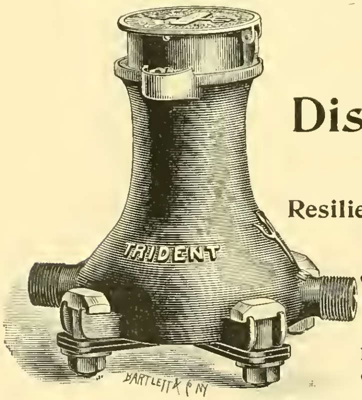

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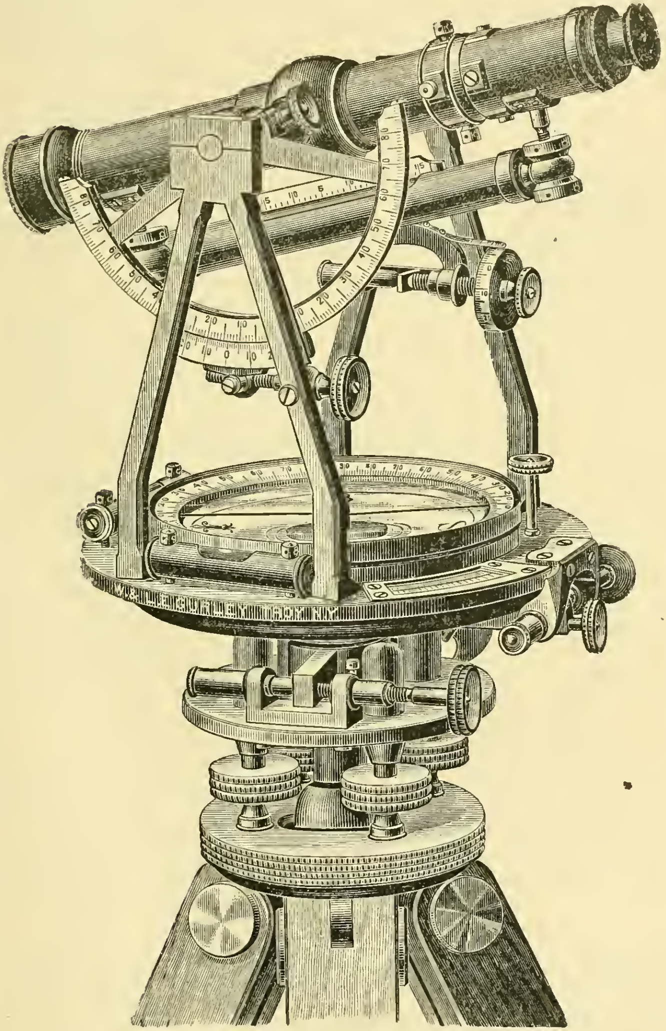
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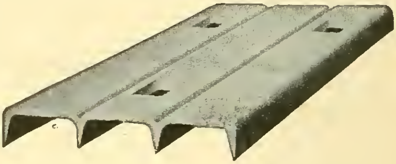

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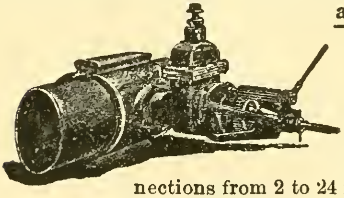

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AMERICAN
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1852

Published at the House of the Society, 220 West Fifty-seventh Street, New York,
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Vol. XXVII. OCTOBER, 1900. No. 8.

PROCEEDINGS

OF THE

AMERICAN SOCIETY OF CIVIL ENGINEERS.

Edited by the Secretary, under the direction of the Committee on Publications.

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Vol. XXVI. OCTOBER, 1900. No. 8.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PROCEEDINGS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

SOCIETY AFFAIRS.

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MINUTES OF MEETINGS.

OF THE SOCIETY.

October 3d, 1900.—The meeting was called to order at 8.40 P. M.; Vice-President Rudolph Hering in the chair; Charles Warren Hunt, Secretary; and present, also, 71 members and 10 visitors.

The minutes of the meetings of September 5th and 19th were approved as printed in *Proceedings* for September, 1900.

A paper by David A. Molitor, M. Am. Soc. C. E., on "The Theory and Practice of Precise Spirit Leveling," was presented in abstract by the Secretary, who also read a written communication on the subject by Herbert M. Wilson, M. Am. Soc. C. E. The subject was also briefly discussed by Mr. Hering.

Messrs. J. H. Myers, Jr. and M. E. Evans, Assoc. Ms. Am. Soc. C. E., were appointed tellers to canvass ballots on the following proposed amendment to the Constitution.

Amend Article VII, as follows:

SECTION 2. * * * Strike out this section and substitute the following:

"2.—At the Annual Meeting of each year, seven Corporate Members, not officers of the Society, one from each of the geographical districts, shall be appointed by the meeting to serve for two years; who, with the five living last Past-Presidents of the Society, shall be a committee to nominate officers for the Society.

"The Board of Direction may prescribe the mode of procedure for appointing this Committee.

"The Committee so appointed shall meet at the Annual Convention of the Society, and nominate candidates to fill the offices, named in Article V, so as to provide, with the officers holding over, a Vice-President and six Directors residing in District No. 1, and twelve Directors divided equally, with regard to number and residence, among the remaining districts, Nos. 2, 3, 4, 5, 6 and 7.

"A list of nominees for the offices to be filled at the next Annual Election shall be presented by the Committee to the Board of Direction within ten days after the nominees have been selected."

The tellers reported the vote as follows:

In favor of the Amendment	193
Against Amendment	53
Total votes	246

The Chairman declarded the amendment adopted.

The Secretary read the list of nominees * presented by the Nominating Committee for the offices to be filled at the next annual election.

Ballots were canvassed, and the following candidates were declared elected.

AS MEMBERS.

FREDERICK CHRISTIAN HOLBERG ARENTZ, Lafayette, Ind.
ARCHIBALD SMITH FREW, Queensland, Australia.
LOUIS CHARLTON FRITCH, Washington, Ind.
WARREN ALLSTON LELAND, Columbus, S. C.
ALEXANDER HAMILTON WEBER, Havana, Cuba
EDWARD LOWREY WOODRUFF, Milwaukee, Wis.

AS ASSOCIATE MEMBERS.

JAMES GARNETT BASINGER, New York City.
ROMEO THOMPSON BETTS, New York City.
RICHARD DAVENPORT CHASE, Brooklyn, N. Y.
BRYAN CHEVES COLLIER, New York City.
WILLIAM HUGH COVERDALE, Pittsburg, Pa.
FRANCIS HENRY DILLON, Saltillo, Coahuila, Mexico.

---

* See page 219.

THOMAS ALVIN GILKEY, Pueblo, Colo.
RICHARD HENWOOD GILLESPIE, New York City.
THOMAS GORDON JANNEY, Centerville, Idaho.
JULIUS KAHN, Tokio, Japan.
WILLIAM HENRY LUSTER, Jr., Elizabeth, N. J.
PERCIVAL ROBERT MOSES, New York City.
HENRY NELSON PHARR, Memphis, Tenn.
ARTHUR DICKSON PRINCE, New York City.
ROBERT MAITLAND ROY, Hamilton, Canada.

The Secretary announced that the following candidates were elected by the Board of Direction, October 2d, 1900.

AS ASSOCIATES.

ERNEST ROBINSON ACKERMAN, New York City.
JACOB HERBERT SAWYER, Chestnut Hill, Mass.

AS JUNIORS.

RAYMOND EDMOND ADAMS, Philadelphia, Pa.
WALTER HINDS ALLEN, Durango, Mexico.
EUGENE BRADFORD BUMSTED, Jersey City, N. J.
ARTHUR MORTIMER DAY, New York City.
HORACE DE REMER HAIGHT, Detroit, Mich.
EDWARD EASTMAN MINOR, New Haven, Conn.
LAZARUS WHITE, New York City.

Adjourned.

October 17th, 1900.—The meeting was called to order at 8.30 P.M., Vice-President Whinery in the chair; Charles Warren Hunt, Secretary, and present, also, 74 members and 11 visitors.

A paper by Octave Chanute, Past-President Am. Soc. C. E., entitled "The Preservation of Railway Ties in Europe," was read by the Secretary, and discussed orally by Messrs. J. J. R. Croes, W. Boardman Reed, E. P. North, George W. Tillson, Mendes Cohen, S. Whinery, Ward Baldwin and H. J. Howe.

The Secretary announced the death of George Dana Emerson, elected Member September 18th, 1872; died September 28th, 1900.

Adjourned.

OF THE BOARD OF DIRECTION.

(Abstract.)

October 2d, 1900.—8.10 P. M.—Vice-President Hering in the Chair; Charles Warren Hunt, Secretary; and present, also, Messrs. Knap, Morison, Noble, Ricketts, Schneider, Seaman, Turner, Whinery, Wisner.

A report was received from a Committee appointed to report on the status of the Juniors elected prior to the adoption of the present Constitution.

The report of the Nominating Committee was received.*

Resignation of Robert Gordon, M. Am. Soc. C. E., was presented and accepted.

The date of the next monthly meeting of the Board was fixed as Friday, November 2d, 1900.

Applications were considered and other routine business considered.

Two candidates for Associate and nine for Junior were elected.

Adjourned.

ANNOUNCEMENTS.

In accordance with the resolution of the Board of Direction the House of the Society is open every day, except Sunday, from 9 A. M. to 10 P. M.

MEETINGS.

Wednesday, November 7th, 1900.—8.30 P. M.—A regular business meeting will be held. Two papers will be presented for discussion: "Canals Between the Great Lakes and New York," by Joseph Mayer, M. Am. Soc. C. E., and "The Economic Dimensions for a Waterway from the Great Lakes to the Atlantic," by George Y. Wisner, M. Am. Soc. C. E.

These papers are printed in this number of *Proceedings*.

Wednesday, November 21st, 1900.—8.30 P. M.—The discussion of the subject introduced by the papers of Messrs. Mayer and Wisner will be continued.

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* See page 219.

LIBRARY CATALOGUE.

It is hoped that the Catalogue of the Library will soon be ready for distribution. Members who wish to have this volume bound in the usual standard binding can do so by notifying the Secretary before November 1st, 1900. The volume will be uniform in size with recent volumes of *Transactions*.

LIST OF NOMINEES FOR THE OFFICES TO BE FILLED AT THE ANNUAL MEETING, JANUARY 16th, 1901.

The following list of nominees for the offices to be filled at the annual election, January 16th, 1901, were presented by the Nominating Committee to the Board of Direction at its meeting on October 2d, 1900, and announced at the meeting of the Society on October 3d, 1900. The list has already been mailed to all Corporate Members.

For President, to serve one year.

J. James R. Croes, New York City.

For Vice-Presidents, to serve two years.

Henry S. Haines, New York City, representing District No. 1.
George H. Benzenberg, Milwaukee, Wis., representing District No. 5.

For Treasurer, to serve one year.

Joseph M. Knap, New York City, representing District No. 1.

For Directors, to serve three years.

Josiah A. Briggs, New York City, representing District No. 1.
George F. Swain, Boston, Mass., representing District No. 2.
Emil Kuichling, Rochester, N. Y., representing District No. 3.
Mordecai T. Endicott, Washington, D. C., representing District No. 4.
Frank C. Osborn, Cleveland, Ohio, representing District No. 5.
Frank C. Carter, Chicago, Ill., representing District No. 5.

MONTHLY LIST OF RECENT ENGINEERING ARTICLES OF INTEREST.

(September 13th to October 10th, 1900.)

NOTE.—*This list is published for the purpose of placing before the members of the Society the titles of current engineering articles, which can be referred to in any available engineering library, or can be procured by addressing the publication directly, the address and price being given wherever possible.*

LIST OF PUBLICATIONS.

In the subjoined list of articles references are given by the number prefixed to each journal in this list.

(1) *Journal*, Assoc. Eng. Soc., 257 South Fourth St., Philadelphia, Pa., 30c.
(2) *Proceedings*, Eng. Club of Phila., 1122 Girard St., Philadelphia, Pa.
(3) *Journal*, Franklin Inst., Philadelphia, Pa., 50c.
(4) *Journal*, Western Soc. of Eng., Monadnock Block, Chicago, Ill.
(5) *Transactions*, Can. Soc. C. E., Montreal, Que., Can.
(6) *School of Mines Quarterly*, Columbia Univ., New York City, 50c.
(7) *Technology Quarterly*, Mass. Inst. Tech., Boston, Mass., 75c.
(8) *Stevens Institute Indicator*, Stevens Institute, Hoboken, N. J., 50c.
(9) *Engineering Magazine*, New York City, 30c.
(10) *Cassier's Magazine*, New York City, 25c.
(11) *Engineering* (London), W. H. Wiley, New York City, 35c.
(12) *The Engineer* (London), International News Co., New York City, 35c.
(13) *Engineering News*, New York City, 15c
(14) *The Engineering Record*, New York City, 12c
(15) *Railroad Gazette*, New York City, 10c.
(16) *Engineering and Mining Journal*, New York City, 15c.
(17) *Street Railway Journal*, New York City, 35c.
(18) *Railway and Engineering Review*, Chicago, Ill.
(19) *Scientific American Supplement*, New York City, 10c.
(20) *Iron Age*, New York City, 10c.
(21) *Railway Engineer*, London, England.
(22) *Iron and Coal Trades Review*, London, England.
(23) *Bulletin*, American Iron and Steel Assoc., Philadelphia, Pa.
(24) *American Gaslight Journal*, New York City. 10c.
(25) *American Engineer*, New York City, 20c.
(26) *Electrical Review*, London, England.
(27) *Electrical World and Electrical Engineer*, New York City, 10c.
(29) *Journal*, Society of Arts, London, England.
(30) *Annales des Travaux Publics de Belgique*, Brussels, Belgium.
(31) *Annales de l'Assoc. des Ing. Sortis des Ecôle Spéciales de Gand*, Brussels. Belgium.
(32) *Memoirs et Compt Rendu des Travaux*, Soc. Ing. Civ. de France, Paris, France.
(33) *Le Génie Civil*, Paris, France.
(34) *Portefeuille Economique des Machines*, Paris, France.
(35) *Nouvelles Annales de la Construction*, Paris, France.
(36) *La Revue Technique*, Paris, France.
(37) *Revue de Mecanique*, Paris, France.
(38) *Revue Générale des Chemins de Fer et des Tramways*, Paris, France.
(39) *Railway Master Mechanic*, Chicago, Ill.
(40) *Railway Age*, Chicago, Ill., 10c.
(41) *Modern Machinery*, Chicago, Ill.,, 10c.
(42) *Transactions*, Am. Inst. Elec. Eng., New York City, 50c.
(43) *Annales des Ponts et Chaussées*, Paris, France.
(44) *Journal*, Military Service Institution, Governor's Island, New York Harbor, 75c.
(45) *Mines and Minerals*, Scranton, Pa. 20c.
(46) *Scientific American*, New York City, 10c.
(47) *Mechanical Engineer*, Manchester, England.
(48) *Zeitschrift des Vereines Deutscher Ingenieure*, Berlin, Germany.
(49) *Zeitschrift für Bauwesen*, Berlin, Germany.
(50) *Stahl und Eisen*, Duesseldorf, Germany.
(51) *Deutsche Bauzeitung*, Berlin, Germany.
(52) *Rigasche Industrie-Zeitung*, Riga, Russia.
(53) *Zeitschrift des oesterreichischen Ingenieur und Architekten Vereines*, Vienna, Austria.
(54) *Den Tekniske Forenings Tidsskrift*, Copenhagen, Denmark.
(55) *Ingeniören*, Copenhagen, Denmark.
(56) *Teknisk Tidskrift*. Stockholm, Sweden.
(57) *Teknisk Ugeblad*, Christiania, Norway.
(58) *Proceedings*, Eng. Soc. W. Pa. 410 Penn Ave., Pittsburg, Pa. 50c.
(59) *Transactions*, Mining Institute of Scotland, London and Newcastle-upon-Tyne.
(61) *Proceedings*, Western Railway Club. 225 Dearborn St., Chicago, Ill., 25c.
(62) *American Manufacturer and Iron World*, 59 Ninth St., Pittsburg, Pa.
(63) *Minutes of Proceedings*, Inst. C. E London, England.

NOTE.—There are no references made in this month's list to German and Swedish periodicals.

LIST OF ARTICLES.

Bridge.

Low-Level Concrete Bridge over the Mary River, Maryborough, Queensland.* Alfred Barton Brady, M. Inst. C. E. (63) Pt. III.
Moving Loads on Railway Underbridges.* William Bean Farr, Assoc. M. Inst. C. E. (63) Pt. III.
Hydraulic Method of Sinking Cast-Iron Piles.* (18) Sept. 15.
Pontoon Swing Bridges over the River Weaver at Northwich, England. John Arthur Saner. (13) Sept. 20.
Reinforcing the Newburyport Suspension Bridge.* (14) Oct. 6.
A Seventy-One Ton Plate Girder. (14) Oct. 6.
Théorie Générale des Poutres Vierendeel.* M. A. Vierendeel. (32) August.

Electrical.

Electric Transmission Plants at Moodie's, De Kaap Goldfields, Transvaal. Henry James Shedlock Heather, Assoc. M. Inst. C. E. (63) Pt. III.
On the Production of Asymmetrical Alternating Currents by means of Electrolytic Polarization. Walter Leo Hildburgh. (6) July.
How Can Central Stations Earn Larger Revenues? Albert B. Herrick. (27) Serial beginning Sept. 1, ending Sept. 15.
Electrical Travelling Cranes. Claude W. Hill. (26) Sept 7.
The Electricity Supply of Glasgow.* (12) Sept. 14.
New Switches for Electric Motors in Mines.* (22) Sept. 14.
New Automatic Motor-Starting Switches.* (47) Sept. 15.
Central Battery Telephone System. (27) Sept. 15.
Telephone Trunk Circuit. (27) Sept. 15.
Regulation in Long Distance Power Transmission by Electricity. F. A. C. Perrine. (24) Sept. 17.
The Ethics of Insulating Materials. J. Wright. (26) Sept. 21.
Wireless Telephony. Sir William Henry Preece. (26) Sept. 21.
Overhead Construction with Special Reference to Guard Wire. Sydney Woodfield. (26) Sept. 21.
The Electric Fountains at the Paris Exposition.* (27) Sept. 22.
Storage Battery—Its Use on Small Roads. B. B. Van Nostrand. (17) Sept. 22.
Railway Power Transmission. J. H. Armstrong. (17) Sept. 22.
Motor-Driven Lathes.* (26) Sept. 28.
Interior Wiring. G. C. Allingham. (26) Sept. 28.
Storage Batteries in Railway Power Stations. Prof. H. H. Norris. (17) Sept. 29.
Systems and Apparatus for Light and Power Distribution. C. P. Steinmetz. (27) Serial beginning Sept. 29, ending Oct. 6.
Electric Cables for High-Tension Service: How They Are Made and Tested in the United States.* William Maver, Jr. (10) Oct.
Electric Plant at Windber, Pa.* A. S. M'Allister. (45) Oct.
Some Gearing for Electric Motors. Alfred H. Gibbings, M. Inst. E. E. (10) Oct.
Mistakes in the Rating of Incandescent Lamps. Arthur J. Rowland. (3) Oct.
Electric Traveling Cranes. A. D. Williams. (62) Oct. 4.
Rotary Transformer Stations. R. E. Danforth. (17) Oct. 6.
Combination Lighting and Traction Plant, Southport, England.* (27) Oct. 6.
The Storage Battery—Its Use in Railway Plants. Thomas Henning. (17) Oct. 6.
Burning Pulverized Coal. (18) Oct. 6.
The Street Railway System of Kansas City.* (27) Oct. 6.
Notice sur les Tramways de Limoges.* M. Delage. (43) Second trimestre.
Le Chemin de Fer Electrique de l'Exposition de 1900.* M. A. Cahen. (38) August.
Les Transports Électriques de l'Exposition: Chemin de Fer Électrique et Plate-Forme Mobile.* Alfred Boudon. (33) Serial beginning Sept. 15, ending Sept. 22.

Marine.

Steamers for Winter Navigation and Ice-Breaking. Robert Runeberg, Assoc. M. Inst. C. E. (63) Pt. II.
The Propelling Machinery of a Torpedo-Boat Destroyer. William David Seton Brown, Stud. Inst. C. E. (63) Pt. III.
Flooding of the New Dry Dock Excavation at the Boston Navy Yard.* Frank O. Maxson, M. Am. Soc. C. E. (14) Sept. 22.
The Damage to the *Oregon*.* (46) Sept. 29.
The French Navy.* (19) Oct. 6.

Mechanical.

Corrosion of Marine Boilers. John Dewrance, M. Inst. C. E. (63) Pt. III.
Mean Effective Temperatures a Unit of Comparison for Heat Engines. Charles E. Lucke. (6) July.
High Power Single-Cylinder Engines at the Paris Exhibition. E. Kilburn Scott. (26) Sept. 7.
Wigzell's Double Triple-Expansion Engine.* (11) Sept. 7.
Lathes at the Paris Exhibition. (11) Sept. 14.
The Comparative Cost of Generating Power by the Steam Engine, Water Turbine, and Gas Engine. John B. C. Kershaw. (11) Serial beginning Sept. 14, ending Sept. 21.

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* Illustrated.

Mechanical—(Continued).

Boiler Explosions on the Thames. (11) Sept. 14.
Mechanical Stoking.* (19) Serial beginning Sept. 15, ending Sept. 29.
Engine Breakdowns.* Michael Longridge. (47) Sept. 15.
Mammoth Lathe for Turning Granite Columns.* (20) Sept. 20.
A Modern Force Pump: Specifications of a Pump with a Wide Range for a Blast Furnace.* (62) Sept. 20.
On Screw Threads Used in Cycle Construction, and for Screws Subject to Vibration. O. P. Clements. (12) Sept. 21.
A 600-H. P. Two-Stroke Cycle Gas Engine Using Blast Furnace Gas. (13) Sept. 27.
Report of Screw Gauge Committee of the British Association, 1900. (29) Sept. 28.
Compressed Air Motors. H. D. Cooke. (17) Sept. 29.
Precision in Steam Power Making. A. S. Mann. (17) Sept. 29.
Regulating Device for Air Compressing Engines.* (47) Sept. 29.
Report on Screw Gauges. (47) Sept. 29.
The Centralisation of the Steam-Condensing Plant.* Harry G. V. Oldham. (9) Oct.
The Thousand-Miles Automobile Trials.* W. Worby Beaumont. (9) Oct.
Recent American Steam-Engine Practice.* James B. Stanwood. (10) Oct.
The Paris Exhibition: Machine Tools, Cranes, Boilers and Engines.* Joseph Horner. (10) Oct.
Suction Air Chambers for Pumps.* F. Meriam Wheeler. (10) Oct.
Water Cooling Towers.* J. A. Reavell. (10) Oct.
Care of Boilers. (45) Oct.
Can Boiler Explosions Be Prevented? W. H. Wakeman. (41) Oct.
Gas Engine Design.* E. J. Stoddard. (41) Oct.
The Westinghouse Gas Engines.* (19) Oct. 6.
Machine à Vapeur Verticale, à Triple Expansion et à Grande Vitesse.* (34) Sept.

Metallurgical.

The Protection of Blast Furnace Linings. S. S. Hartranft. (20) Sept. 13.
The Problem of Machine Molding. E. H. Mumford. (20) Sept. 13.
Suggestions for the Improvement of Rolling Mills. Louis Katona. (22) Sept. 21.
The Present Position of the Solution Theory of Carburised Iron. A. Stansfield. (22) Sept. 28.
The Constitution of Slags and the Part They Play in the Metallurgy of Iron. Baron Juptner von Jonstorff. (22) Sept. 28.
The Smelting Corporation's Works at Ellesmere Port, England.* L. F. Vogel. (16) Sept. 29.
Influence of Aluminium on the Carbon in Cast Iron. Godfrey Melland and Harry W. Waldron. (47) Sept. 29.
New Bessemer Mill.* (62) Oct. 4.
The Present Condition of the Metallurgy of Iron in Europe. Emile Demenge. (16) Oct. 6.
Steel Castings. (18) Sept. 22.
Les Aciers Moulés à l'Exposition de 1900.* A. Abraham. (33) Serial beginning Sept., 15, ending Sept. 22.

Military.

Krupp's Modified Welin Breech Screw.* (12) Sept. 7.
The New Army 16-in. Gun.* (46) Sept. 29.

Mining.

Electric Locomotives in Coal Mining. (11) Sept. 7.
Pit Props and Their Setting. (22) Sept. 7.
Gold Mining in Nova Scotia.* G. W. Stuart. (16) Sept. 15.
Shaft Sinking on Potassium Salt Deposits. E. Mackay-Heriot. (16) Sept. 22.
The Columbia Mining Company, Georgia.* W. H. Fluker. (16) Sept. 22.
On a New Method of Sinking Pits by Machinery.* Richard Sutcliffe. (22) Sept. 28.
Colliery Trams. J. Fox Tallis. (22) Sept. 28.
Coal Mine Maps. L. C. Morganroth. (16) Sept. 29.
The Quartz Lodes of the Atlin District, B. C.* R. H. Stretch. (16) Sept. 29.
Experimental Ore Testing Works. Prof. Arthur Lakes. (45) Oct.
Iowa Coal-Mining Methods.* J. T. Beard. (45) Oct.
Limonite Ores of Pennsylvania; Their Composition and Forms and an Account of the Various Places Where They Are Mined in the State.* T. C. Hopkins. (45) Oct.
Pere Marquette Mines: A Description of One of the Largest and Best Equipped Coal Mines in the State of Michigan.* R. A. Randall. (45) Oct.
Tunnel Developments at Cœur d'Alene. W. C. Clark. (45) Oct.
Mining Methods in the Connellsville Coke Region.* F. C. Keighley. (9) Oct.
Copper Mining in Northern Wisconsin. Kirby Thomas. (45) Oct.
The Haile Gold Mines: Machinery Used for Concentrating the Ores and for Roasting and Treating them by the Chlorination Process. Prof. Arthur Lakes. (45) Oct.
Georgia Gold Mining Developments.* Wilber Colvin. (16) Oct. 6.

Municipal.

Economics of Street Paving. S. Whinery. (14) Serial beginning August 11, ending August 18.

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* Illustrated.

Municipal—(Continued).

Present Problems in Municipal Engineering.* Thomas De Courcy Meade, M. Inst. C. E. (14) Serial beginning Sept. 1, ending Sept. 15.
Motors for Street Watering and Dust Removal. E. Shrapnell Smith. (11) Sept. 14.
Construction of Granite Block Pavements. Josiah A. Briggs. (14) Sept. 15.
The Construction of Standard Medina Block Stone Pavements. E. A. Fisher. (14) Sept. 15.
Laying a 24-in. Gas Main across the Harlem River.* G. H. P. M'Vey. (46) Sept. 15.
Construction and Maintenance of Brick Pavements. E. A. Kemmler. (14) Sept. 22.
Chemical Fire Engine.* (12) Sept. 28.
The Reduction of the Cost of Distribution (of Gas) by the Use of High Pressures. Frederick H. Shelton. (24) Oct 1.

Railroad.

Selangor Government Railway. Guilherme Henrique Fox, Assoc. M. Inst. C. E. (63) Pt. II.
Maintenance of Railway Tunnels * Arthur Watson, M. Inst. C. E. (63) Pt. II.
The Construction of the Simplon Tunnel.* Charles Beresford Fox, Stud. Inst. C. E. (63) Pt. II.
Failures in the Draw and Buffing-Gear of Railway Wagons.* George Tertius Glover. (63) Pt. III.
The Pressed Steel Car, with Some Experiences in Erecting them in Egypt.* Sumner B. Ely. (58) June.
Machinery for the Garesfield and Derwenthaugh Incline Railway.* (11) Serial beginning July 13, ending July 27.
Loss of Strength During Service of Steel Rails. (21) Sept.
A Remarkable Roundhouse—Chicago & Northwestern Railway.* (39) Sept.
The City and South London Railway.* (26) Sept. 7.
Automatic Block Signal Failures due to Lightning. H. D. Miles. (18) Sept. 8.
Pneumatic Signalling Plant at the Paris Exhibition.* (11) Sept. 14.
Ditching Machine on the Chicago Great Western.* (18) Sept. 15.
Derailments. J. H. Wallace. (18) Sept. 15.
New Interlocking Electric Switch and Signal System.* J. R. Cravath. (27) Sept. 15.
Railway Transition Curves. F. K. Vial. (13) Sept. 20.
The "Gibraltar" Bumping Post.* (40) Sept. 21.
Malleable Iron for Tramcar Details. (26) Sept. 21.
Arch Construction for Railroads.* J. W. Rollins, Jr. (18) Sept. 22.
The "Solid" Coupler.* (15) Sept. 28.
The Taylor Electric Switch and Signal Apparatus.* (15) Sept. 28.
The Effect of Temperature on the Friction of Brake Shoes.* (15) Sept. 28.
Measurement of the Tractive Force, Resistance and Acceleration of Trains.* A. Mallock (12) Sept. 28.
Recent Tramway Construction; with Special Reference to the Demerbe System. William Dawson. (26) Sept. 28.
Rochester & Sodus Bay Railway Company. T. J. Nicholl. (17) Sept. 29.
"Northwestern Type" Passenger Locomotive, Chicago & Northwestern Railway.* (25) Oct.
Locomotive Design. F. J. Cole. (25) Oct.
Hot Journals.* (25) Oct.
A Locomotive with "Helping Cylinders" at the Paris Exposition.* (13) Oct. 4.
An Automatic Coupler for English Freight Cars.* (13) Oct. 4.
New Shops of the Hannibal & St. Joseph Railroad.* (15) Oct. 5.
Building the Pressed Steel Car. (15) Oct. 5.
The Stresses in Arch Bar Frames (for Diamond Frame Trucks).* George I. King. (15) Oct. 5.
Note sur les Nouvelles Machines Compound à Grand Vitesse, de la Compagnie du Nord.* M. Du Bosquet. (38) August.

Sanitary.

Tropical Sanitation, with Special Reference to Hong Kong. Robert Gervase Alford, M. Inst. C. E. (63) Pt. III.
The Vacuum System of Low-Pressure Steam-Heating. Edward George Rivers, Assoc. M. Inst. C. E. (63) Pt. II.
The Treatment of Leeds Sewage. (12) Sept. 7.
Municipal Sewerage Systems and Assessments. Geo. T. Bouton. (14) Sept. 22.
Bradford's Refuse Destructors. (62) Sept. 27.
The Sewerage Works at Flemington, N. J.* (14) Sept. 29.
The Concord Sewage Pumping and Electric Station.* (14) Oct. 6.
Plumbing in a Detached Manufacturing Plant.* (14) Oct. 6.
Assainissement de Mexico.* (36) Sept. 10.

Structural.

The Whitehall Portland Cement Works.* (14) Sept. 15.
The Testing of Portland Cement.* W. C. Popplewell. (47) Sept. 15.
American Standard Specifications and Methods of Testing Iron and Steel. Albert Ladd Colby. (22) Sept. 21.

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* Illustrated.

Structural—(Continued).

Foundations of the Alliance Building.* (14) Sept. 22.
Corrosion of Wrought Iron and Steel. Henry M. Howe. (47) Sept. 22.
The Creo-Resinate Wood-Preserving Plant.* (14) Sept. 22.
A Novel French Method of Making Foundations in Soft Ground. (13) Sept. 27.
The New York Clearing House Dome.* (14) Sept. 29.
Concrete and Expanded Metal Floor Tests. A. T. Walmisley. (14) Oct. 6.
Constructions en Béton Armé: Principales Applications et Avantages Caractéristiques.* M. G. Flament. (32) August.
Déformations et Conditions de la Rupture dans les Corps Solides.* M. Harel de la Noé. (43) Second trimestre.

Water Supply.

The Construction of the Elan Aqueduct: Rhayader to Dolau.* Herbert Lapworth, Stud. Inst. C. E. (63) Pt. II.
Turbines.* Arthur Henry Tyack, Stud. Inst. C. E. (63) Pt. III.
The Water Power at Holyoke, Mass.* Horatio A. Foster. (1) August.
The Wachusett Dam.* (14) Serial beginning Sept. 8, ending Sept. 15.
The Wachusett Dam for the Metropolitan Water Supply, Boston, Mass.* Alfred D. Flinn, Assoc. M. Am. Soc. C. E. (13) Sept. 13.
Water Supply, with a Description of the Bradford Water-Works. James Watson, M. Inst. C. E. (11) Sept. 14.
Water Waste and Use in Washington. Capt. D. D. Gaillard. (14) Sept. 22.
Repairing a Submerged Water Main. (14) Sept. 22.
Screens and Screen Lifters; Metropolitan Water-Works, Boston and Vicinity.* Chas. W. Sherman, Assoc. M. Am. Soc. C. E. (13) Sept. 27.
Experiments on the Flow of Water Over Dams.* (13) Sept. 27.
Asphalt and Brick Reservoir Linings.* (14) Oct. 6.
The New Pumping Station and Water Tower in Vienna.* (14) Oct. 6.
Les Forces Hydrauliques des Alpes en France, en Italie et en Suisse. René Tavernier. (43) Second trimestre
Réservoir de 3 000 Métres Cubes de Capacité en Ciment Armé de Metal Déployé.* (36) Sept. 10.

Waterways.

A Short History of the Engineering Works of the Suez Canal.* Sir Charles Hartley, M. Inst. C. E. (63) Pt. III.
High-Water Protection Methods on Lower Mississippi River. William Joseph Hardee, M. Am. Soc. C. E. (1) August.
Hydraulic Hopper Dredges for the East Channel, New York Harbor.* (14) Sept. 22.
Test Borings for the Isthmian Canal Commission. (14) Sept. 29.
Rules for Heavy Concrete Work. (14) Sept. 29.
The Projected Improvement of the Southwest Pass.* William Starling, M. Am. Soc. C. E. (13) Oct. 4.
The Sea-Going Hydraulic Dredge *Benyaurd.* (14) Oct. 6.
Note sur le Nouveau Système de Fermeture des Écluses à Grande Chute du Canal de Roanne à Digoin. M. Mazoyer. (43) Second trimestre.
Les Dragues.* M. R. Masse. (37) August.
Drague Marine à Godets, á Succion et à Refoulement.* (33) Sept. 15.

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* Illustrated.

NEW BOOKS OF THE MONTH.

Unless otherwise specified, books in this list have been donated to the Library by the Publisher.

SOUVENIR, VICTORIA JUBILEE BRIDGE.

Opened for Traffic December Thirteenth, Anno Domini Mdcccxcviii. Metal covers, 8 x 6 ins., unpaged, illus. Montreal, 1900. (Donated by the Grand Trunk Railway System.)

This is an account of the construction of the Victoria Jubilee Bridge and of the Victoria Tubular Bridge which it replaced.

STREET PAVEMENTS AND PAVING MATERIALS.

A Manual of City Pavements: The Methods and Materials of Construction. For the Use of Students, Engineers and City Officials. By Geo. W. Tillson, M. Am. Soc. C. E. Cloth, 9 x 6 ins., 532 pp., illus. New York, John Wiley & Sons, 1900. $4.00.

The author's main idea in preparing this work has been to have it practical, so that an engineer unacquainted with the subject could obtain sufficient information to prepare specifications for, and intelligently supervise the construction of, pavements. The Contents are: The History and Development of Pavements; Stone; Asphalt; Brick-Clays and the Manufacture of Paving-Brick; Cement, Cement-Mortar and Concrete; The Theory of Pavements; Cobble and Stone-Block Pavements; Asphalt Pavements; Brick Pavements; Wood Pavements; Broken-Stone Pavements; Plans and Specifications; The Construction of Street-Car Tracks in Paved Streets; Width of Streets and Roadways, Curbs, Sidewalks, etc.; Asphalt Plants. There is an index of thirty-six pages.

THE LAW OF OPERATIONS PRELIMINARY TO CONSTRUCTION IN ENGINEERING AND ARCHITECTURE.

Rights in Real Property. Boundaries, Easements, and Franchises. For Engineers, Architects, Contractors, Builders, Public Officers, and Attorneys at Law. By John Cassan Wait, M. Am. Soc. C. E. Sheep, 9 x 6 ins., 638 pp. New York, John Wiley & Sons, 1900. $5.50.

The author states in the preface that this work treats of the law attending those operations which precede construction. Such operations are those required for the determination of data and information which should be obtained before a project is undertaken. The Contents are: Part I, Property. Estates in, and Title to, Real Property. Part II, Rights and Privileges incident to Ownership of Real Property. Protection of, and Interference with, Rights in Fluids. The Supply and Use of Water, Oil, Gas and Electricity. Rights in Navigable Waters. Interference with Property Rights by Surveyors. Trespass. Part III, Determination of the Boundaries of Land. Surveys and Surveying. Part IV, Easements, Incorporeal Rights. Part V, Franchises. There is an index of fifty pages.

THE THEORY AND PRACTICE OF SURVEYING.

Designed for the Use of Surveyors and Engineers Generally. But Especially for the Use of Students in Engineering. By J. B. Johnson, M. Am. Soc. C. E. Fifteenth Edition. Cloth, 8 x 5 ins., maps, illus. New York, John Wiley & Sons, 1900. $4.00.

The headings of chapters are: Instruments for Measuring Distances; Instruments for Determining Directions; Instruments for Determining Horizontal Lines; Instruments for Measuring Angles; The Plane Table; Additional Instruments Used in Surveying and Plotting; Land-Surveying; Topographical Surveying by the Transit and Stadia; Railroad Topographical Surveying; Hydrographic Surveying; Mining Surveying; City Surveying; The Measurement of Volumes; Geodetic Surveying; Projection of Maps, Map-Lettering and Topographical Symbols. There is an index of twenty pages.

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PAPERS AND DISCUSSIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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CANALS BETWEEN THE LAKES AND NEW YORK.

By JOSEPH MAYER, M. Am. Soc. C. E.

TO BE PRESENTED NOVEMBER 7TH, 1900.*

The reports of the New York Canal Commission on a barge canal between Buffalo and Albany, and of the United States Commission on ship canals 21 ft. deep and 30 ft. deep between Buffalo and New York, giving estimates of cost and other information, enable us, by gauging the probable benefits to be derived from them, to judge the merits of each of these enterprises.

There are advocates who sincerely believe that railroad transportation is cheaper than transportation in narrow waterways. Their opinion is based on the undoubted fact of the abandonment of many canals, and on State subventions received by others which are not abandoned but are doing an increasing business.

The notion that the free play of economic forces would induce private enterprise to build canals, as railroads are built, if they would really furnish a cheap means of transportation, has still great influence on many minds, and creates at least a prejudice which must be

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NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers with discussion in full will be published in *Transactions*.

* The discussion on this paper, in connection with that of Mr. Wisner (see page 989), will be taken up November 7th, 1900, and continued at the meeting of November 21st, 1900.

overcome before they are willing to vote in favor of taxes for their construction.

There are also various enthusiasts, anti-monopolists, and other enemies of railroads, who are in favor of anything that they believe will destroy the monopoly of the latter, regardless of any careful weighing of costs and advantages to be gained.

One erroneous argument, often used by advocates of water transportation, consists in a direct comparison of average freight rates on the Lakes and ocean with the average freight rates of railroads. The average freight rate on the railroads of the United States was in 1899 0.724 cent per ton-mile, while the average freight rate on the Lakes and Atlantic was until recently about one-tenth as much. This comparison, however, is misleading, since a very much larger percentage of the lake freight consists of crude materials than is the case with railroad freight. On the Lakes, ore, grain, coal and lumber form the bulk of the freight, and it would be more correct to compare the average freight rate on the Lakes with the average freight rate on railroads for these articles only.

The average haul on the Lakes and Atlantic is very much more than on railroads; this is another reason why ton-mile rates are lower by water than by rail, since the average rail rates include expensive short-haul freights as well as through freights. If allowance is made for these differences it is found that the freight rate per ton-mile on the Lakes and Atlantic is about $\frac{1}{5}$ and not $\frac{1}{10}$ of the ton-mile rate charged by railroads for similar freight transported over similar distances, with favorable grades, which latter are always obtainable along water routes.

To obtain the average rates for water transportation it is necessary to take a number of years into consideration, since the variations from year to year are much larger than on railroads. Recently all freight rates by water were excessively high, from transient causes, but it is certain that they will shortly recede to the level of the last few years, and probably lower, in consequence of the larger and more economical steamers which are now being built. This ratio of charges of 5 to 1, however, does not quite represent the ratio of cost, since the railroad charges include interest and profit on capital invested in line and terminals and the cost of their maintenance, while the terminal facilities of waterways, and the interlake channels with their lighting, are partly provided by the public without charge, and therefore, the cost incurred ought to be added to the freight rates by water in the proper proportion to obtain a fair comparison with railroad rates.

The endeavor will be made in this paper to show that the arguments based on past experience with canals are inconclusive, and to give the real reason why private capital cannot safely undertake the construction of the canal here considered and count with certainty on receiving the benefits derived from it. It is a necessary condition for the success of human intercourse that he who confers a benefit on others receive an equivalent benefit in exchange. Wherever there is free competition between those providing the different kinds of benefits or goods, and between those desiring them, this offers the means of ascertaining what are equivalent benefits or what is the relative value of different goods.

Where such competition is absent it is extremely difficult, if not entirely impossible, to ascertain what would be an equivalent benefit for a service rendered, or, in other words, what would be a fair charge for the same.

On account of this impossibility of ascertaining what is a fair charge for services which in consequence of their nature exclude competition, public opinion is fluctuating on this point. In any business which is a monopoly seriously affecting the welfare of a very large number of people who can easily co-operate politically, interference with the liberty of charging what the traffic will bear must always be feared, and the probable profits can therefore not be estimated. All those benefits which can be rendered at very much reduced cost, if manufactured on an extremely large scale, limit or entirely exclude competition. All means of transportation belong to this class. A highway will facilitate transportation, and the cost of the unit of benefit rendered by it falls rapidly with the amount of traffic. A fair toll on a highway privately owned would be of such an amount as would give an equal return to the capital invested in its construction as the return obtained by capital invested in competitive enterprises of equal risk, and managed with the same amount of skill.

This needs only to be stated to show the impossibility of ascertaining what is a fair toll when the highway is constructed without sufficient public control to show the amount of capital really expended, not to speak of the difficulty of judging the risk and the skill used in the enterprise.

So many interests are affected by the amount of the tolls collected on highways, and the usefulness of a highway is so much reduced by the collection of uniform tolls of any size, that highways, where they have been built by private enterprise, have mostly been expropriated and the tolls abrogated.

Private railways are not quite as precariously situated as either highways or canals.

In a rapidly developing country, if a State regulates the railroad charges so that they pay no fair return on the capital invested, railroad building or improvement of facilities is stopped, and this is soon felt to be such an obstacle to further growth that public opinion becomes more favorable to railroads, and permits them to profit by the increase in traffic. It is further evident that competition very largely influences many railroad charges; they are therefore not arbitrary, and in consequence there is a strong element in public opinion advocating that they be left alone, which succeeds in greatly tempering public interference.

It is felt more and more that the only fair way to fix the compensation of the various factors contributing to the creation of public benefits outside the range of competition is to induce the capitalists to furnish their contribution, not by promising them the net earnings which they might get by managing the enterprise and charging what the traffic will bear, but by promising the smallest rate of interest for which the capital is obtainable in the open market, and compensating the various grades of labor by wages and salaries in the same manner as the capitalist would have to do. The *entrepreneur* is in this case the public, which is then at liberty to charge for the services rendered whatever is thought most advantageous for the public welfare.

A private company which would propose to build a canal between the lakes and New York would, in the present state of public opinion, probably be unable to obtain a charter, and should it obtain one it would be so entirely at the mercy of the public, in respect to the charges which would be permitted, that it probably could not raise the necessary capital.

The proposed project, if we consider now that recommended by the United States Commission, of a canal 21 ft. deep and 215 to

250 ft. wide at the bottom, through the Niagara River from Buffalo to Lasalle, thence by eight locks to Lewiston, then through Lake Ontario to Oswego, from there to Lake Oneida and through the Mohawk Valley to the Hudson, is a waterway that would permit free access from all the Lakes to the ocean, for vessels 550 ft. long, 58 ft. beam and 19 ft. draft; it would make them available in winter, and would thereby reduce cost of local transportation on the Lakes; it would connect the harbors serving the most productive regions of the United States with each other by an unobstructed waterway, avoiding transfer of freight from lake vessels to canal boats, and from these to ocean steamers.

There are only three waterways which approach this one in the nature and magnitude of the services rendered—the Suez Canal, the Sault Ste. Marie Canal and the waterway between Lakes Huron and Erie. While the Suez Canal saves thousands of miles of distance, or the two transfers and a short railroad haul, which would be necessary in its absence, the three other canals of this class save transfers at each end which, with the attendant charges or costs, the delays in loading and unloading, and the risks of damage to goods, are economically considered equivalent to thousands of miles of distance.

Isolated canals suffer from the disadvantage that their cheap transportation is overbalanced by the necessity of transfers for all the freight either coming from or going to points which they do not reach. They might be called transfer canals, while the four canals above grouped together are transit canals.

The canals of Europe, where they are successful, are parts of large systems, thereby increasing the number of points accessible without transfer; they stand, therefore, more nearly on an equal footing with railroads in this respect. They form an intermediate link between the isolated canals creating transfers and the canals connecting large systems of water transportation which save transfers.

This difference is sufficiently important to vitiate all inferences drawn from the failure of canals of one class to the prospects of those of another.

The cost of running a vessel though the proposed ship canal between Buffalo and New York is no mystery. The practicable speed is known by experience with other canals of similar dimensions. Leaving for later consideration the interest on cost of canal and its operating expenses, it is sufficiently accurate to say that the cost per ton-mile of running a vessel through the canal is larger than that on the lakes in the proportion that the time required to pass through the canal is larger than that for an equal distance on the Lakes. The speed of the newer freight steamers on the Lakes is about twelve miles per hour; the speed through the St. Clair flats canal, of dimensions similar to those of the canal proposed between the Lakes and the Hudson, is over eight miles per hour, as found by actual measurements by the United States Canal Commission. To estimate the increase in cost of transportation due to this reduction in speed it is important to separate the total cost of transportation into two parts, the one due to the running of the vessel, which increases as the distance, and the other due to the expenses at terminals, which is dependent on the number of trips, and is not materially affected by an increase in the time spent while running. For trips between the Upper Lakes and Buffalo not more than two-thirds of the expenses of vessel owners are incurred for running the vessels between terminals. The ship canal between Buffalo and New York, proposed by the United States Canal Commission, has 102 miles of canal of standard section and 96 miles of canalized river in which the bottom width varies between 250 and 1 000 ft. If we assume for the whole length of restricted channel, amounting to 198 miles, a speed of 8 miles an hour, which can be exceeded in some parts of it, the time required for passing through this channel would be 24.75 hours, or the same as would be required for a distance of 297 miles on the open Lakes, an increase over actual distance of 99 miles. The delay caused by the 37 lockages would be equal to 23 hours, which would be sufficient to cover 276 miles in the open Lakes. The time required for going from Chicago to New York, an actual distance, *via* the proposed canal, of 1 367 miles, would be the same as that required for covering a distance of 1 742 miles on the open Lakes.

The average charge on the Lakes for low-class freight between Chicago and Buffalo was, in the years before the recent abnormal rise, below 50 cents a ton, of which 33.3 cents only is due to the distance to be covered, and 16.7 cents is due to terminal expenses incurred by carrier. If these terminal expenses of carrier remain the same, the only increase in total freight charge to New York over that to Buffalo will be due to the increased time required in going from Chicago to New York instead of to Buffalo. The increase is as 890 miles to 1 742 miles, and the charge for transportation proper would, therefore, be 65.3 cents per ton instead of 33.3 cents. If we add to this the charge of 16.7 cents due to terminal expenses of carrier, we obtain 82 cents per ton as the probable future charge for low-class freight from Chicago to New York. This is at the rate of 0.60 mill per ton-mile for the actual distance of 1 367 miles.

This rate is nearly identical with the rate per ton-mile between Chicago and Buffalo ruling before the recent rise in lake freight rates, and corresponding to 50 cents a ton between the latter points.

This illustrates the great advantage of the absence of transfers; the terminal expenses, being distributed over a greater number of ton-miles, decrease the total rate per ton-mile as much as it is increased by the slower speed on the canal.

Any comparison of actual ocean, lake or railroad rates between points of widely varying distances will show, other things being equal, that the ton-mile rate decreases with the distance. Between San Francisco and Europe the ton-mile rate falls sometimes to 0.03 cent for grain and 0.02 cent for coal returning; while between New York and Europe ton-mile rates twice as high prevail. This clearly shows that a large percentage of the freight charge is due to terminal expenses.

The above rate of 82 cents per ton, Chicago to New York, is the charge toward which the actual freight rate might be expected to gravitate, after the profits in the business, which would at the beginning probably be excessive, should have fallen to a normal amount. The same rate, increased by 4 cents per ton for every hundred miles distance from New York, might be expected to rule between Chicago and places beyond New York.

Six days would be the time required for the transport of through freight between Chicago and New York.

This quick time, and the absence of transfers, would have the effect that a large amount of high-class freight could be secured, for which the present charge is, by rail, $6 to $15 per ton, according to class.

The freight charge for wheat, Chicago to New York, corresponding to the above rate of 82 cents per ton, is 2.46 cents per bushel. Through the present Erie Canal the charge for wheat, Chicago to New York, was in 1898, 4.82 cents per bushel. The saving would therefore be 2.36 cents per bushel in comparison with the cheapest and slowest method of transportation now available. Since the freight tonnage of the New York State canals is only about 5% of that of the railroads crossing the State, it is more reasonable to compare the charges for freight through the new canal with the lake and rail and with the all-rail rates now existing between Chicago and New York. The lowest average lake and rail rates for wheat ruled in 1898, when they were 5.4 cents per bushel. The lowest average all-rail rate is given at 10 cents per bushel; 6 cents per bushel has, however, sometimes ruled from Chicago to the seashore.

In comparison with lake and rail rates, the saving on the new canal, offering far better service, would be 2.94 cents per bushel.

For wheat going to points on the Atlantic coast which cannot be reached by present canal boats, or to Europe, the transfer in New York could be avoided by the use of ocean steamers loading at upper lake ports. Not only the transfer charges in New York would thereby be saved, but the costs due to the loss of time of both carriers engaged in the transfer, and the total saving in comparison with present charges for transport from upper lake points to all points beyond New York and immediate vicinity, would be over 5 cents per bushel, or $1.67 per ton.

Advocates of a barge canal between New York and Buffalo lay much stress on the low cost of barges and lake vessels per ton of carrying capacity in comparison with ocean steamers, and by assuming that an ocean steamer or lake vessel would have to go at the rate of 4 miles an hour between New York and Buffalo, and would remain as long at terminals as a canal boat, they figure out advantages for a shallow canal with the present system of transfers. Their assumptions are, however, not justified by the facts. The disadvantage of ocean steamers arising from the necessity of a stronger hull than is required for lake steamers, and from the use of surface condensers has been greatly exaggerated by comparing the cost of fast and durable ocean steamers with that of much slower and short-lived lake steamers, without making allowance for these differences. The difference in cost that does exist in this respect is overbalanced by the fact that the ocean steamer can run for 12 months in the year, while the lake steamer is limited to an open season of 8 months. The interest charge per month of running time is therefore less for an ocean steamer than for a lake steamer of equal carrying capacity, equal speed and durability.

A lake steamer can give only transient employment to its *personnel* during a season of the year when wages are high, while the ocean steamer can give permanent employment, and obtains, therefore, a cheaper service.

Ocean freight rates are, in consequence, rather lower than freight rates on the lakes. Canal boats costing only $8 per ton carrying capacity could not safely go beyond the canal. They would obtain in a barge canal a speed of only 4 miles per hour; the thereby increased cost of labor per ton-mile, and the delays due to transfers of freight more than balance the advantages gained by lower interest charge.

Should a canal of the kind proposed by the United States Canal Commission be built, the through freight business between the lake points and transatlantic countries would be done largely by medium-sized ocean steamers, while lake steamers and coasting vessels would do the through business between lake points and the Atlantic coast harbors, and barges might be used for local business. Even the local business done in barges could be done much cheaper in a ship canal than in a barge canal, because the practicable speed in the former would be twice that in the latter.

In regard to the amount of business which could be expected for such a canal, it need only be mentioned that were it finished now, 200 000 000 bushels of wheat and its products, and 250 000 000 bushels of corn, or 12 250 000 tons in these two items alone, would probably be transported through it in an average season. Adding to these, other grains, ore, coal, lumber, salt, stone, cement and the large amount of high-class freight which might be expected, it is evident that 20 000 000 tons is a low estimate of the probable freight per year shortly after its opening.

The traffic of the Sault Ste. Marie Canal has doubled every six years during the last twenty-four years; it was 25 000 000 tons in 1899. If we compare the productivity and population, or the tonnage visiting the harbors at both ends of the Sault Ste. Marie Canal, with those at both ends of the canal between the lakes and New York, we can hardly believe that the latter will have a smaller amount of freight than the former.

The Detroit River has at present an estimated traffic of over 40 000-000 tons. There can be little doubt that the more eastern canal, having the whole lake region at one end and the coasts of the Atlantic at the other, would soon reach and exceed this amount.

A comparison of the traffic of 8 500 000 tons of the Suez Canal, connecting a population of 700 000 000 in the East with one of 400 000 000 in the West, with the traffic of the interlake waterways, which mainly serves the trade of a population of only 40 000 000, gives a striking illustration of the small amount of trade between distant old world nations in comparison with a fraction of the internal trade of a part of the United States.

The internal trade of the United States is more than ten times its foreign trade. The internal transportation costs about twenty times as much as that for the foreign trade. This explains why these internal waterways secure such an enormous traffic in comparison with the population they serve. By far the largest part of the traffic through a canal between Buffalo and New York would be traffic between the Atlantic coast harbors of the United States and the interior of the country.

There can therefore be no doubt that the saving in cost of transportation would benefit the United States principally. The only benefit Europe would derive from it would follow after the higher prices for grain in the West had so stimulated production as to largely increase exports, and reduce European prices in consequence, and after the decreased prices of European products in the West had increased the demand for them, so as to produce a rise of prices in Europe.

Since the canal cannot be finished before six years have elapsed, any estimates of its traffic based on the present business of the interlake channels would have to be increased at least 50%, since this increase may reasonably be expected in their traffic during this time. It would therefore be advisable in construction to make provision for duplicating the locks in the near future.

The capacity per season of the canal proposed by the United States Canal Commission is 36 000 000 tons; its estimated cost, inclusive of deepening of interlake channels to 21 ft., is $200 000 000.

Allowing one-eighth of the cost for interest during construction, and taking interest at 3%, the yearly cost would be $6 750 000, plus the cost of maintenance, which latter is estimated at $2 350 000 per year.

A very moderate toll, in comparison with the saving in cost of transportation, would cover all expenses incurred by the nation. The saving to the public in freight charges would probably average $1.50 a ton in consequence of the advantages which uninterrupted and quick transportation would offer to high-class freight.

The whole district, not alone along the canal, but the whole lake and Atlantic coast of the United States, would thereby become unequaled in its accessibility to raw materials and markets. The lake basin, having the cheapest steel of any shore, would then become the principal shipbuilding center of the world.

The rapid increase of business on the Lakes, as well as through this canal, would undoubtedly create a demand for greater depth in the lake harbors and larger cross-section in the interlake channels and in the canal, and this prospect should be kept well in view during the planning and construction of the same.

It might even be advisable, considering the improvements in lake channels and harbors which may be expected during the next twenty years, to build the canal 24 ft. deep, instead of selecting dimensions which will be just sufficient for accommodating the vessels which will exist in the Lakes at the time of its completion. This would give, from the beginning, the advantage of permitting greater speed than would be possible on the smaller canal. The larger locks to accommodate the vessels on this larger canal would also give a larger carrying capacity, which will almost certainly be needed before twenty years of its operation have expired.

To sum up: The ship canal between the Lakes and New York proposed by the United States Commission is a transit canal connecting without transfer two large systems of important harbors; it is therefore in the class of canals which have been most successful in the past.

It connects the two most productive regions in the world, and will therefore soon have a traffic equal to the proposed capacity of 36 000 000 tons a year.

The yearly cost of the canal will be $9 100 000, which is about 25 cents per ton of freight which will soon pass through it.

The saving in cost of transportation will average about $1.50 per ton in comparison with the cost of equally good service at present available. Most of this saving will accrue to the United States, which should therefore undertake its construction.

A toll adequate to cover all the cost will not materially interfere with its usefulness, and will serve to distribute justly the burden of the expense on those who gain by its construction.

There is at present under way a survey for a barge canal of 12 ft. depth, the cost of which has been estimated at about $59 000 000 by the New York Canal Commission. It is proposed that the State of New York shall build it for the purpose of securing its commercial supremacy. The route is that of the present Erie Canal, with some deviations; the estimated capacity is 20 000 000 tons per season. It is hoped that the transfer charges at Buffalo and New York will be largely reduced in consequence of the building of such a canal. It is estimated that the saving in cost of transportation through the whole length of this canal, in comparison with the cost through the present Erie Canal, will be 61 cents per ton, which would, in the opinion of the Commission, amply compensate the State for its expenditures for construction and maintenance. It is not proposed to levy any tolls.

The difference in the cost of transportation on the present and improved canal is calculated by estimating the cost, running expenses and carrying capacity per season, of a new style of barge, with which there is no practical experience, and comparing this with the actual cost of transportation through the present Erie Canal.

This method is evidently subject to a great many errors, even if used by investigators who are not in any way prejudiced in favor of a particular result.

An illustration of the amount of difference between facts and estimates of this kind is furnished by the estimate made by Major Symons, M. Am. Soc. C. E., of the New York Canal Commission, on page 81 of a report to the Chief of Engineers of the United States Army in 1897, on a canal between Buffalo and New York. He there gives ten as the practical number of round trips per season between Buffalo and New York for a vessel of 20 ft.-draft, in a canal 24 ft. deep, on the Oswego route. The United States Canal Commission gives sixteen as the practicable number of round trips per season between Chicago and New York, for a vessel of 19 ft. draft in a canal 21 ft. deep, on the Oswego route. This latter estimate is based on careful observation of the actual speed of similar vessels in a canal of the same dimensions as the one proposed between Buffalo and the Hudson, on the observed speed in the open Lakes, and on the actual performances of lake vessels. This gives

15 days $7\frac{1}{2}$ hours for one round trip, of which 6 days are required for the forward and return passage between Buffalo and Chicago. This leaves 9 days $7\frac{1}{2}$ hours as the time required, according to their estimate, for one round trip between Buffalo and New York, and would permit twenty-six round trips per season between these points, with 3 days to spare in the average open season.

The practicable number of round trips is the most essential element in all the estimates of cost of transportation in various kinds of canals between Buffalo and New York, made by Major Symons.

This throws considerable doubt on the accuracy of his calculations of the saving in cost of transportation to be expected from an improved barge canal.

But let us assume, for the sake of argument, that the estimate of the New York State Canal Commission, of the difference in cost of transportation in the present and the improved Erie Canal, is correct, and let us investigate whether the conclusion drawn therefrom, that it is advisable for the State of New York to execute the improvement, is justified by the premise.

If the public provides, at its own cost, a new means of transportation, or an improvement in an old one, cheapening cost of transport by a certain amount, various freight will be transported that would not have been transported at all in the absence of the improvement, and other freight is deflected from other means of transport, though the advantage thereby secured may be very trifling, but just sufficient to turn the balance in its favor. It is therefore a serious error to estimate the advantage to the public achieved by an improvement in the Erie Canal, by multiplying the difference in cost of transportation per ton in the old and new canal with the number of tons passing through the new canal, and subtracting therefrom the expenses incurred by the public for construction and maintenance. This method is only correct for freight which would pass through the Erie Canal in its present condition. This tonnage of the present Erie Canal is constantly decreasing, in consequence of the continually falling railroad rates.

The average saving on freight, either newly created or diverted from other transportation lines, will be liberally estimated if assumed to be 0.6 of the amount of 61 cents, or 36.6 cents per ton.

If the taxpayers of the State of New York are expected to provide an improvement, it is reasonable for them to ask whether their benefit from it is likely to compensate them for the expense. An improved Erie Canal, lowering the cost of transport and the transfer charges, would undoubtedly largely increase the amount of freight passing through it, originating at, and destined for, points outside New York, but the saving on this part of its freight traffic would only slightly benefit New Yorkers.

Of the freight, either exported from New York State or imported into the State through the canal, half the saving in cost of transport might be expected to represent the benefit to New Yorkers. The following method will, therefore, give the balance of advantage and expense of an improved barge canal from the standpoint of New Yorkers.

Take the whole saving on the present amount of local freight of canal originating at, and destined for, points in New York State. The average distance traversed by this freight on canal is not known, but will not be underestimated if taken to be three-fourths of its length. The saving on this freight would therefore be three-fourths of 61 cents, or, say, 46 cents per ton.

Take half the saving of cost of transportation on the present canal business originating in, or destined for, points in New York State. If we estimate the distance traversed by this freight on canal as three-fourths of its total length, the saving to New Yorkers on this freight would be 23 cents per ton. For new business created by the improvement take 0.6 of the amounts above given.

Neglect the through business originating at, and destined for, points outside the State. Then compare the sum of advantages so obtained in one year with the yearly expenses incurred for maintenance and interest on cost of improvement. If there is a large surplus on the right side the State may be justified to commit the unavoidable amount of injustice which lies in collecting taxes in proportion to assessed value of property while the benefits are very unequally distributed among the whole population.

Should the total freight carried by the canal be equal to its capacity of 20 000 000 tons, the freight with origin and destination outside New York would be at least 10 000 000 tons; the remainder, not more than 10 000 000 tons, would partly have both origin and destination in New York, and partly only one of them. We can only guess at the relative amount of these two parts; we shall therefore take them to be equal.

Of these latter two parts about one-eighth would have to be taken as the successor of the corresponding freight on the present Erie Canal.

The saving for New Yorkers would, therefore, be as follows:

On 625 000 tons of freight corresponding to the freight on the present Erie Canal, with origin and destination in New York, 46 cents per ton, equal to..	$237 500
On 625 000 tons of freight corresponding to freight on present Erie Canal, with either origin or destination outside New York, 23 cents per ton, equal to..	118 750
On 4 375 000 tons of new freight, with origin and destination in New York, 0.6 of 46 cents, or 27.6 cents per ton, equal to..............................	1 207 500
On 4 375 000 tons of new freight, having either origin or destination in New York, 0.6 of 23 cents, or 13.8 cents per ton, equal to............	603 750
The total saving to New Yorkers, due to the cheapening of transportation on the improved Erie Canal, if the tonnage on the same were equal to its capacity, would therefore be................	$2 167 500

We have estimated that 10 000 000 tons would be through freight, saving two transfers, or benefiting by reduction in cost of two transfers, probably partly the one and partly the other; and 5 000 000 tons would be freight benefiting by reduction in cost, or avoidance of one transfer. Half of the benefit from reduction in transfer cost on these 5 000 000 tons would accrue to New Yorkers.

The present cost of these transfers is 70 cents per net ton for two transfers; if one-half of this cost were saved the New Yorkers would benefit to the extent of $437 500.

If we add this amount to the saving in the cost of transport, we obtain $2 605 000 as the possible saving which might be obtained for New Yorkers through the improved canal, should its business be equal to its capacity.

Against this stand the interest charges on the money spent on the improvement and the cost of maintenance, which latter may be estimated at $1 500 000 per year. The estimate of cost of the improvement is \$59 000 000. This does not include interest during construction and the first years of use, when business would be much smaller. If we add 12% to the estimate of cost on this account, we obtain \$65 600 000 as the actual cost to the taxpayer ; 3% interest on this is \$1 968 000.

The yearly cost would therefore be about \$3 468 000, against a benefit to New Yorkers of \$2 605 000.

Should the business of the canal be only 10 000 000 tons, which seems to be the estimate of the New York State Canal Commission, the total benefit to New Yorkers would be about \$1 500 000, at a cost more than twice the amount.

The above does not pretend to be an accurate estimate, as that is impossible; it is only intended to prove that even if the difference in cost of transportation on the present and improved Erie Canal were 61 cents per ton, if the improved canal would secure all the freight it could carry, and if it would be the means of reducing transfer charges one-half, none of which favorable assumptions is either proved, or even probable, the State of New York would not be justified in undertaking the improvement at its own cost.

This whole question must be looked at, not from the narrow point of view of the State of New York and its particular interest, but from that of the interest of the United States. Modern trade is regardless of State boundaries, and it is impossible to benefit the State without benefiting the Union, or to benefit the Union in this matter, without benefiting New York State.

By the fact that every point along the canal is practically a harbor, or can easily be made one, the State must always profit, as a center of manufactures, by any improvement in its waterway, more than either the shores of the Lakes or the Atlantic, since only comparatively few points along these shores, namely, those with harbors, are put in direct communication by this waterway.

The main service of this waterway does not consist in cheapening transportation along its course, though this also will be accomplished more efficiently by a ship canal than by any other, but in removing the necessity of transfers at both ends.

The present transfer charges are only the smaller part of the total cost incurred on account of these transfers. Transfer or transit means all the difference between slow and inefficient service, excluding all except the lowest class freight, and in great danger of losing even this on account of the rapidly falling rail freight rates, and quick, safe and reliable service, by through transportation lines, at such low cost as to be beyond the reach of railway competition, either in quality of service or price for the same, between all the points which can be directly reached.

A ship canal between Buffalo and New York means the creation of one great system of water transportation out of two of half the size; it means that each harbor of each of the two systems will have on an average twice as many points to which it can ship directly by water as it had before. Its opening will be the signal for a renewed period of rapid increase in the shipping of the Atlantic coast as well as the lakes.

A toll of 20 cents a ton for each transfer saved by the freight passing through this canal would not amount to more than one-quarter of the benefit derived from this saving, if the improvement in quality of service made possible thereby is properly valued. It would cover all expenses incurred by the nation.

Since the main reason for the large cross-section of canal, and the great expense caused thereby, is the saving of transfers, it would be just to charge tolls in proportion to the number of transfers saved.

The proper course for New York State is, therefore, to abandon its policy of desiring a canal all by itself, and to join in hearty co-operation with the other interests desiring a ship canal.

If it refuses to do so, there is serious risk that the various interests which are principally concerned in having the cheapest possible communication between the West and Europe, will join forces to build a ship canal from the Lakes to Montreal, which could be built at a cost quite commensurate with the services rendered thereby; though these would not compare with those rendered by a canal through New York, which would also serve the much larger and more important trade between the West and the East of the United States.

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THE ECONOMIC DIMENSIONS FOR A WATERWAY FROM THE GREAT LAKES TO THE ATLANTIC.

By George Y. Wisner, M. Am. Soc. C. E.

To be Presented November 7th, 1900.*

The economic depth for canals of large traffic was discussed in the *Transactions* for June, 1898,† but as the data did not exist at that time on which to base comparative estimates of cost of canals of different dimensions for the routes under consideration, it was impossible to fix the limiting depth where the fixed charges for maintenance and interest on the cost of construction would make the actual transportation rate greater than for lesser depths of channel.

Plans and estimates have been made since then for regulating works to control the level of Lake Erie, and for constructing waterways 21 ft. and 30 ft. deep through the connecting channels of the Great Lakes, and from the Lakes to the Atlantic.

A preliminary estimate of a barge canal 12 ft. deep from Buffalo to New York has been made, and while the best location and exact cost

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NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers with discussion in full will be published in *Transactions*.

* The discussion on this paper, in connection with that of Mr. Meyer (see page 972), will be taken up on November 7th, 1900, and continued at the meeting of November 21st, 1900.

† *Transactions*. Vol. xxxix, page 273.

cannot be stated until the surveys now being made under the direction of the State Engineer are completed, it is safe to say that the estimate made by the New York State Committee on Canals will not be changed sufficiently to materially affect the present discussion.

In previous discussions of the proposed waterway from the Lakes to the seaboard the depth of channel has been made the important factor and but little consideration given to the economy in transportation rates due to the different speeds which may be maintained by steamers in waterways of different dimensions.

For instance, in Major Symons' able report on a Ship Canal from the Great Lakes to the sea it is estimated that lake freighters of 16 ft. and 20 ft. draft would make only four miles per hour in a waterway 24 ft. deep, and that the time required at terminal ports would be from 11 to 12 days, or about the same as the sailing time of round trip; while in a barge canal 12 ft. deep, with a cross-section of 1 200 sq. ft., steam canal boats with three to five consorts in tow would be able to make practically the same number of round trips per season.

To anyone familiar with the speeds maintained by steamships in the artificial channels of our lake waterways, and with the rapidity with which cargoes are loaded and discharged at terminal ports, it seems like begging the question to draw conclusions from transportation rates based on such assumptions.

The St. Clair Flats Canal is 7 200 ft. long, 20 ft. deep at mean stage of Lake St. Clair, and has a cross-section of about 5 700 sq. ft. or 200 sq. ft. greater than the cross-section of the proposed 21-ft. waterway from the Lakes to the Atlantic for which plans and estimates have recently been made.

It has been found from actual observations that the large freighters on the Lakes can safely navigate the canal at speeds of from 7 to 11 miles per hour without slackening speed when passing other steamers in the waterway.

There is an average current of about 1.7 miles per hour in the canal, which makes navigation much more dangerous than it would be in a canal with no current except that required for the necessary water supply, yet no serious accident has ever occurred in the waterway.

Lake freighters, capable of steaming 12.5 statute miles per hour in the open lake, make from 23 to 24 round trips per season between Duluth and Buffalo, or an average of one round trip every ten days, three days of which are due to time consumed in loading, unloading, coaling and making repairs at terminal ports.

If the detentions at the terminals of a ship canal between the lakes and New York should amount to ten or twelve days per round trip, it is safe to say that but little freight would be discharged at New York except that consigned directly to the city, a condition which would unquestionably develop methods of handling cargoes such that the detentions need be but little greater than at lake ports.

The Suez Canal had a cross-section of 3 700 sq. ft. previous to the enlargement now being made, through which the speed for large steamers was restricted to 6.2 statute miles per hour.

In the Amsterdam Canal, with a cross-section of 4 000 sq. ft. the speed is limited to 5.6 miles per hour.

In the Kiel Canal, having a cross-section of 4 100 sq. ft., a speed of 6.2 miles per hour is allowed, but the larger ships only average about 5 miles per hour.

Speeds of 6 miles per hour are allowed for large ships in the Manchester Canal where the cross-section is 4 400 sq. ft., but, owing to the sharp curves in the canal, tugs are used for towing the larger steamers.

The limit of speed for these canals has been fixed with reference to preventing injury to the banks, but is not very different from the economical speeds which could be maintained by large steamers in waterways of such dimensions.

The retardation of the speed of a ship in a restricted waterway is due to the resistance of the sides and bottom of channel to the movement of the water displaced by the steamer, to the velocity of back flow of the displaced water, and to the back pressure of the water piled up in the channel in front of the moving ship.

It has been found from actual observations of the speeds of steamers on the Great Lakes that a ship capable of averaging 12.5 miles per hour in the deep water of the open lakes is retarded about 16%, or 2 miles per hour, when steaming with the same boiler pressure and only 2 ft. of water under the keel.

When the lake channels are improved so as to allow the passage of ships of 19 ft. to 20 ft. draft, the cross-section of the St. Clair Flats Canal will be about six times that of a loaded freighter, and the mean back flow due to the movement of the ship will be about one-fifth of the speed of the steamer. It is, therefore, apparent that where the cross-section of the waterway is less than six times that of the passing ship the speed will be retarded at least one-third of that which could be maintained in open water.

The dimensions which should be given a waterway between the lakes and the Atlantic depends upon the economic depth which can be obtained and maintained in the water routes to be connected.

The depth of channels at the entrances of lake harbors before improvement was only about 3 ft. to 10 ft., and across the shallows of the connecting waterways about 9 ft. to 13 ft.

The project of improvement now being carried out contemplates channel depths of about 21 ft. for mean lake stage, but as yet only about 18 ft. has been secured. The question to be settled is, what is the depth which can be economically given these channels such that ships able to safely weather the lake storms may be passed at all times, and that the fixed charges for maintenance and interest on cost shall not exceed the benefits to be derived from the reduction in rates of transportation and from developing new industries and commerce?

During the heavy storms which are of frequent occurrence in the fall of the year on the Lakes, large freighters drawing less than 17 ft. when loaded, have not been found well adapted for safe navigation, which fixes the minimum limit of depth of channels at about 20 ft.

For greater depth of channels than 20 ft. the advisability of improvement will depend upon whether the benefits to be derived will be equivalent to the fixed charges arising from maintenance and cost of construction.

At the head of Lake Erie, through Lake St. Clair, and at the foot of Lake Huron and Lake Superior there are extensive flats where the water is only about 21 ft. deep at average stage, and if the connecting channels should be made a greater depth, nearly 60 miles of the route through the rivers and lakes would be excavated channel.

The cost to the Government to deepen the lake channels for depths of over 21 ft. will be about $3 000 000 per foot, and to improve the lake harbors and entrances correspondingly will cost about $4 000 000 per foot, or a total of $7 000 000 for each additional foot of depth in harbors and waterways. Assuming that the Government pays 3% for the money expended on improvements and one-half of 1% for maintenance, the annual fixed charges for each additional foot of depth would be approximately $245 000.

The actual freight carried on the Lakes in 1899 was not far from 40 000 000 tons, and if the annual fixed charges arising from making and maintaining deeper waterways should be chargeable to the entire amount of traffic, the saving in transportation rates would have to exceed six mills per ton for each foot of improvement to make the accounts balance.

The actual saving in the cost of transportation on the Lakes by using deeper draft vessels is only about one-half the above estimated fixed charges, and therefore the improvement would be advisable only on the supposition that the indirect benefits from developing new industries and new commerce will be of greater value to the country than the total decrease in the cost of transportation. This could hardly hold true as the decrease in rates would be permanent, while the effect of the improvement in developing new commerce would likely be of only a few years' duration.

It is true that the fixed charges arising from interest on the cost of waterway improvements and from expense for operation and maintenance are paid by the Government, but whether paid from Government revenues or from toll on traffic the net result is the same, and should be considered in the comparison of transportation rates, especially with those on railroads where such expenses are paid directly from the earnings.

If we take into consideration the fact that ships of more than 500 ft. length cannot be safely handled in the sharp curves of the connecting waterways of the Lakes, that with a draft of 18 to 19 ft., ships not exceeding such length can safely navigate the Lakes at all seasons, and that for greater depths of channels than 21 ft. the interest and maintenance account will exceed any expected returns from lower transportation rates, there seems to be no legitimate reason why the ultimate depth for lake waterways should not be definitely settled at once.

While it is true that the small freighters of the Lakes must go out of business and make way for the more economical type carrier, it is also true that a continual change of dimensions of waterways renders the smaller ships practically obsolete long before worn out, and since the rate at which freight can be carried depends upon the probable useful life of the ships, continual changes in the type of freight carriers will materially increase the cost of transportation.

If the freight business on the Lakes can be conducted as economically with waterways 21 ft. deep as with channels of greater depth, the waterway from the Lakes to the Atlantic should not exceed such depth unless it can be shown that the benefits to be derived from through transportation between the Lakes and foreign ports in deep draft ships will be of sufficient importance to warrant the larger expenditure required to construct a canal of corresponding dimensions.

Tables Nos. 1 and 2 give the details of the length of channels of different dimensions, the amount of lockage, and the estimated cost of waterways 21 ft. and 30 ft. deep from Buffalo to New York *via* the Oswego-Mohawk and St. Lawrence-Champlain routes, and are abstracted from the report of Board of Engineers on Deep Waterways.

TABLE No. 1.—BUFFALO TO NEW YORK.

	*OSWEGO-MOHAWK ROUTE.		CHAMPLAIN ROUTE.
	High level plan.	Low level plan.	
Total distance, miles	477.04	476.94	685.21
Fall, regulated stage of Lake Erie to mean tide, feet	574.5	574.5	574.5
Down lockage, feet	742.6	705.6	547.2
Up “ “	170.6	133.6	0.0
Total lockage, “	913.2	839.2	547.2
Number of locks	39	37	19
“ “ guard locks	1	1	2
Standard canal, miles	102.56	102.42	102.35
Canalized river—			
200 to 250 ft. bottom width, miles	....	....	1.51
250 to 300 “ “ “	20.38	20.38	....
300 to 350 “ “ “	12.37	12.37	38.97
350 to 400 “ “ “	2.59	2.59	....
400 to 450 “ “ “	13.90	13.90	8.08
450 to 500 “ “ “	8.99	8.99	11.59
500 to 1 000 “ “ “	39.15	37.65	73.65
Open lake and river	277.10	278.64	449.06
Total Miles	477.04	476.94	685.21

* Note: In the high level plan for the Oswego-Mohawk Route the water supply is to be obtained from reservoirs in the Black and Salmon River Valleys, and in the low level plan Oneida Lake is to be used as a reservoir, with a deep cut for the waterway between Oneida Lake and the Mohawk River.

TABLE No. 2—Estimated Cost of Waterways.

	30-Ft. Channel.	21-Ft. Channel.
Lake Superior to Lake Erie........	$33 539 869	$6 961 818
Lake Michigan to Lake Erie.......	16 226 548	1 466 439
Lake Erie to Lake Ontario.........	73 435 350	42 393 203
Lake Ontario to New York—		
Oswego-Mohawk Route (High Level Plan)...............	206 253 553	155 324 968
Oswego-Mohawk Route (Low Level Plan)...............	210 309 129	157 003 082
St. Lawrence Champlain Route.	213 123 864	141 027 415
Duluth to New York—		
Oswego-Mohawk Route (High Level Plan)...............	313 228 772	204 679 989
Oswego-Mohawk Route (Low Level Plan)...............	317 284 348	206 358 103
St. Lawrence-Champlain Route.	320 099 083	190 382 436
Chicago to New York—		
Oswego-Mohawk (High Level Plan).....................	295 915 451	199 184 610
Oswego-Mohawk (Low Level Plan).....................	299 971 027	200 862 724
St. Lawrence-Champlain Route.	302 785 762	184 887 057

The Committee on Canals of New York State, in its report to the Governor of New York, estimate that a barge canal from Buffalo to the Hudson River, 351 miles long, 12 ft. deep, with a cross-section of 1 200 sq. ft. will cost $58 894 668.

The Canadian government has expended about $65 000 000 upon the construction and maintenance of the St. Marys, Niagara and St. Lawrence canals, or about $13 per capita for the entire population of the country. This amount, however, does not represent the cost to construct the canal system as now completed, as nearly the entire system on the Niagara and St. Lawrence Rivers has been enlarged from two to three times. The canals are 14 ft. deep, with locks 270 ft. long and 45 ft. wide, and were intended to develop through transportation between the Lakes and Montreal.

The expectations relative to the volume of traffic that would be developed have not been realized, and it is extremely improbable that the small type of steamer which can pass the locks will be able to compete with the large lake freight carriers, even when handicapped with excessive transfer charges at Buffalo.

It will be noted that the length of standard canal is practically the same by the Mohawk or Champlain routes, and that the 208 miles greater distance by the latter route is mostly through the wide channel of the Lakes and rivers.

The Champlain route is a down-grade waterway from the Lakes to the seaboard, and has 366 ft. less lockage than the Mohawk high level route, and for a 21-ft. channel will cost $14 300 000 less than the latter.

It is fair to assume that in a 21-ft. waterway with an area of cross-section practically the same as the St. Clair Flats Canal, the speed of ships in straight reaches will be fully as great as that of the larger lake freighters in the St. Clair Canal. Making the necessary reductions for slower speed on curves and in passing ships *en route*, and for detentions at locks, it is found that a freighter capable of steaming 12.5 miles per hour in the open lake should make the round trip between Chicago and New York in 11 days and 8 hours *via* the Mohawk Route, and in 12 days and 9 hours *via* the Champlain route.

The navigation season on the Mohawk route will average about 245 days and for the Champlain route 230 days, and if the detention at New York is not more than twice the time required at Buffalo, a lake steamer should make 16 round trips per season between Chicago and New York *via* the Mohawk route and fourteen by the Champlain route. The average sailing time between Chicago and Buffalo for steamers capable of running 12.5 miles per hour in the open lake is about 72 hours, and the estimated time for the same type of steamers between Buffalo and New York based on the actual performance of freighters in similar restricted channels of the lake waterways is 64 hours.

This estimate is based on a 21-ft. waterway having a cross-section of 5 500 sq. ft. area or about six times the midship section of ship, which ratio will allow safe speeds of 8 to 10 miles per hour with the same consumption of fuel required in open water.

In the previous discussion* the Ship Canal is assumed to be 24 ft. deep, with a section of 4 200 sq. ft., and that ships having midship sections of 1 000 sq. ft. would average about 4 miles per hour, not including detentions at locks and terminals.

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* *Transactions*, Vol. xxxix.

In the case of the barge canal the proposed cross-section is 1 200 sq. ft. or four times that of the barge, a ratio which will not admit of average speeds of over 4 miles per hour with ordinary barge fleets.

From these elements it was estimated that steamers in the ship canal, and barge fleets in the barge canal, will only average ten round trips per season between Buffalo and New York, whereas with suitable dimensions for the waterway and proper dispatch in loading and discharging ships at terminals at least 14 to 16 round trips may be made between Chicago and New York, or about three times the annual volume of business estimated in the 1898 discussion for steamers on the ship canal from Buffalo to New York.

The expense account of lake and ocean freighters is so much greater than that for canal barges that an accurate estimate of practical speed in canals and of detentions at terminals is essential in making any comparison of rates at which freight can be carried on the two types of waterways.

In the report of the Committee on Canals of New York State, it is estimated that a ton of freight can be transported from Buffalo to New York on barges for 26 cents, but in obtaining such a result the Committee omits from the expense account the items for interest on cost of construction, annual expenses for repairs and maintenance, and profit for the shipowner.

The interest and insurance expenses are based on a valuation of $28 500 for a fleet of one steamer and three barges, yet in a foot-note on page 19 of the report it is shown that if constructed of steel the fleet would cost $70 000.

With the increase in the cost of lumber which is sure to occur in the near future, the cost of barges constructed of wood will approximate that of steel; but even if this should not be the case, it is probable that the greater cost of towing wooden barges would make the steel barge more economical for transportation at the values given.

At the Brussels International Congress on Navigation in 1898, Captain C. V. Suppan, Chief of the Steam Navigation Service on the Danube, gave the result of some experiments in towing steel and wooden barges of similar models on the Danube, from which it appears that the power required for the wooden barges was nearly twice that required for the steel barges, and that the cost for towing per ton-mile for the wooden barge was about double that for the steel.

If these results are correct, the wooden barge will not be economical, even at a lower value than that given in report.

Correcting the estimate on page 64 of the Report of the Committee on Canals for omissions and for change in values, the expense account for barge fleet, with a total annual traffic on canal of 15 000 000 tons, will be as follows:

TABLE No. 3.—Expense Account Barge Fleets.

Wages and subsistence	$4 000
Fuel, oil, waste, etc	3 300
Ordinary repairs	300
Insurance on fleet, 4½ per cent	3 150
Insurance on cargo	3 900
Miscellaneous expenses	200
Interest on investment, 5 per cent	3 500
Deterioration, etc., 5 per cent	3 500
Fixed charges for maintenance, repairs and interest on cost of canal (3 per cent.)	8 800
Shore expenses and commissions	1 000
Profit to ship-owner	1 500
Total for 52 000 tons	$33 150
Cost of transportation per ton between Buffalo and New York	0.64
Rate on lake, Chicago to Buffalo	0.50
Transfer at Buffalo	0.25
Total rate per ton, Chicago to New York	$1.39
" " bushel, " "	0.042

The rate per ton for both the barge and the ship canal (Tables Nos. 3 and 4) will vary from these estimates with any variation of the volume of traffic from that used. West-bound freight, which has been estimated at one-third of the eastward movement and at the same rate per ton, would, under normal conditions, command a higher rate than the east-bound freight, but with the volume of westward traffic only sufficient for one-third cargoes for the ships in the service, competition would likely

TABLE No. 4.—Dimensions, Capacity and Expenses of a Steamship Adapted for the Traffic of a 21-Ft. Waterway, and Capable of Running 12.5 Miles per Hour in the Open Lake.

Length over all	480 ft.
Breadth	52 "
Draft	19 "
Horse-power, I. H. P.	2 200
Coal consumed per hour, lbs.	3 850
Net carrying capacity, tons	8 600
Cost of ship for lake and canal business only	$360 000
Cost of ship adapted for ocean and lake business	387 000
Pay-roll and subsistence, per day	60
Fuel, oil and waste, per day, when running	117
Fuel, oil and waste, per day, in port	30
Insurance	4½%
Repairs and depreciation	5%
Expenses for season of 245 days:	
Wages and subsistence	$14 700
Fuel, oil, waste, etc.	23 400
Insurance on ship	16 200
Insurance on cargo	22 900
Miscellaneous expenses	1 000
Interest on investment, 5 per cent	18 000
Deterioration, etc., 5 per cent	18 000
Fixed charges for maintenance of canal, repairs and interest on cost (3 per cent.)	73 400
Shore expenses and commissions	2 000
Profit to ship owner	10 000
Total for 183 470 tons	$199 600
Rate per ton, Chicago to New York	$1.09
Rate per bushel, Chicago to New York	0.033

force the rate fully as low as for east-bound traffic. The interest on the cost of the canal during construction would also increase the amount of fixed charges above those used in the estimates and correspondingly increase the rate per ton.

These variations will have relatively the same effect on the rates for both the barge and ship canal, and therefore would not materially change the comparative value of the two types of waterways.

The items from Tables Nos. 3 and 4, for wages, subsistence, fuel and miscellaneous expenses, amount to between one-fourth and one-fifth of the respective total expense accounts, showing that the actual cost of moving a ton of freight from Chicago to New York will be less than one-fourth of the rate necessary to transact the business, and therefore any material reduction in transportation rates can only be obtained by constructing waterways on which quick trips can be made and all unnecessary transfer and terminal charges eliminated.

The comparative transportation rates given in Major Symons' report differ from the present estimate for the reason that the latter includes fixed charges for maintenance and interest, and is based upon speeds in the restricted portions of the waterway which have been demonstrated to be safe and practical in the connecting channels of the Lakes, and upon dispatch at terminal ports similar to that now obtained at Lake harbors.

The average time in port for freighters running between Duluth and Buffalo is about three days per round trip, but to make allowance for the different conditions in New York Harbor four days per round trip have been used in the present estimate.

It is also assumed that if the volume of traffic on the barge canal should amount to 15 000 000 tons annually, a ship canal of dimensions suitable to allow the lake tonnage free passage to the seaboard would develop at least 20 000 000 tons per year.

The record of the transportation rates and volume of traffic on canal and railroads between Buffalo and New York indicate that any waterway which does not admit of steamers passing direct between lake ports and the seaboard is not likely to prove a successful competitor of the railroads.

The freight carried on the Erie Canal:

In 1837 was	667 151	tons.
In 1850 "	1 635 089	"
In 1860 "	2 253 533	"
In 1870 "	3 083 132	"
In 1880 "	4 608 651	"
In 1890 "	3 303 929	"
In 1899 "	2 414 084	"

Since 1880, when the traffic on the Erie Canal reached a maximum, the rate per ton-mile on the railroads from the Lakes to the seaboard has been nearly double that on the Erie Canal, yet during that time the business of the canal has diminished one-half, while that on the railroad has nearly trebled, showing beyond question that the volume of freight which will be shipped by any given route does not depend entirely upon the relative transportation rates, and that unless the causes which have produced the decline of traffic on the Erie Canal are eliminated in the construction of new waterways no better results need be expected.

Two of the principal benefits to be expected from the construction of a waterway of proper dimensions between the Lakes and the Atlantic, are the development of ship-building industries at lake ports, and to make it possible for individual ship owners to do business in competition with combinations, neither of which could be realized from the construction of a 12-ft. barge canal.

The only possible way in which the traffic of a barge canal requiring transfer of freight at Buffalo can be increased over that of the present Erie Canal, will be by organizing large transportation companies to operate fleets of barges in connection with freight steamers on the Lakes, so that through bills of lading can be made from lake ports to the seaboard.

Such an arrangement would also require the control of sufficient elevator capacity at Buffalo to take care of the surplus grain which at times would be greatly in excess of the carrying capacity of the barges.

With economical water transportation only possible for organizations controlling large amounts of capital, it is by no means improbable that the canal and railroad companies would combine to maintain rates, and thereby destroy about the only benefit to be expected from a canal of such dimensions.

In a waterway having dimensions to correspond with the depth of the water routes connected, individual ship owners would have equal opportunities with the large organizations and practically make the control of freight rates impossible.

Such a waterway would also make it possible to increase largely the steel and shipbuilding industries of the country, and probably be of great assistance in restoring the Merchant Marine of the United States in foreign trade.

It is of interest to note that the distance from Buffalo to New York by railroad is 440 miles, by Barge Canal 496 miles, and by ship canal *via* Lake Ontario and the Mohawk River is 477 miles, making the barge route 19 miles longer than the ship canal, with about three times greater amount of canal section through which boats will have to move at minimum speed.

Referring to the estimated cost of 21 and 30-ft. waterways from the Lakes to the seaboard it will be noted that the latter will cost about $100 000 000 more than the former, not including the cost of improving terminal harbors. The difference in expense for operation, maintenance and repairs will be about $550 000 per year, making the fixed charges for a 30-ft. waterway, including the improvement and maintenance of lake harbors, nearly $5 000 000 greater than for one of 21-ft. depth.

It has been shown that taking the cost of improvements into consideration the commerce of the Lakes can be transported more economically with channels of 21-ft. depth than with deeper ones, and therefore whatever advantages are to be derived from a 30-ft. waterway from the Lakes to the Atlantic must come from developing new industries and commerce by direct trade between the Lakes and foreign ports.

With a traffic of 20 000 000 tons annually in such a waterway it is not probable that more than 6 000 000 tons would be foreign commerce, and if carried in deep-draft vessels the 14 000 000 tons for domestic consumption would have to be discharged at New York for use in the city, or for reshipping to other ports on the Atlantic Coast. This would necessitate two-thirds of the ships trading direct between the lake ports and New York, or sailing for Europe with light loads.

With a 21-ft. waterway the ships adapted to the service could discharge domestic commerce at New York or at any other port on the coast to which consigned, but would probably transfer all foreign freight to ocean steamers at New York, except on the last trips before the close of lake navigation, when it might be found advantageous to load for through passage to Europe.

Taking into consideration the annual expenses for interest and maintenance of the two waterways, the cost of transportation for domestic traffic will be 6 cents per ton greater for a 30-ft. waterway than for one 21-ft. deep, from which it would appear that any benefits to be derived from canals of greater depths than necessary for economical transportation on the Lakes must result from direct foreign trade between the lake ports and Europe.

If the difference of the annual fixed charges for the two depths of waterway between Buffalo and New York be charged to the probable volume of foreign traffic, the transportation rate will be about 20 cents per ton greater with a 30-ft. waterway than with a 21-ft. canal.

The amount of transfers at New York for the combined domestic and foreign traffic would be fully as great when transported in deep-draft ships as when carried in steamers adapted for safe navigation of the lake waterways, and therefore the benefits to be expected for the deeper waterway must be wholly of an indirect nature.

Since the interests of the steel and ship-building industries would be equally well subserved by either waterway, it is difficult to conceive of conditions which would warrant the large expenditure necessary to construct a waterway of greater dimension than required for safe and economical navigation on the Lakes.

Almost any transportation rate may be deduced for the routes of different depths, by varying the assumed speed in the restricted channels and the time lost by detentions at terminal ports. If, however, the dimensions of channels be such as to allow economical speeds for the type of vessel adapted to their use, there need be no trouble in establishing these elements of the problem within reasonable limits, as the average speed at which canal barges can be towed is pretty well known, and the safe speeds of steam ships in the restricted waterways of the Great Lakes and in the Ship Canals of Europe furnish data from which the ratio of cross-section of channel to that of ship may be determined, which will give a minimum rate of transportation.

CONCLUSIONS.

1. A waterway from the Great Lakes to the Atlantic to produce the best results should have dimensions which will permit the passage, at economical speeds, of ships best adapted for the traffic of the water routes connected.

2. Safe navigation of the Great Lakes requires a minimum depth for the connecting channels of at least 20 ft. and for depths of over 21 ft. the interest on the cost of construction will exceed the decrease in transportation rates due to the use of deeper draft freight carriers.

3. With any waterway requiring the transfer of freight at Buffalo, independent canal boats cannot compete with existing lake and railroad lines, and unless the waterway is operated by rich transportation companies controlling lines of lake steamers and canal barges, the business developed will probably not exceed that of the present Erie Canal.

4. The decline of traffic on the Erie Canal since 1880, and the failure of the 14-ft. Canadian canals to divert commerce from the lake and railroad lines, indicate that a waterway of less depth than required for the passage of the best type of lake freighters can not materially modify the transportation rates over existing routes.

5. The indirect benefits to commerce to be derived from a 21-ft. waterway will be nearly as great as can be expected with greater depth of channel.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS AND DISCUSSIONS.

Note.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

HEIGHT OF BUILDINGS.

An informal Discussion at the Annual Convention, July 2d, 1900.*

Subjects for Discussion:

(1) "What Considerations Should Limit the Height of Buildings?"

(2) "Do Recent Developments in Construction, Sanitation, Intercommunication and Economy of Administration, warrant the Removal of all Restrictions?"

By Messrs. W. E. Riley, Oscar J. Kirby, H. de B. Parsons, R. J. Gifford Read, J. F. Wallace, R. W. Hunt, Maurice M. Sloan.

W. E. Riley,† M. Inst. C. E.—The views of lower New York were hardly recognized by the speaker, to whom that part of the city was quite familiar twelve years ago. The geographical situation had always appeared to him to be a great difficulty; the narrow tongue of land between the broad East and Hudson Rivers, with the Harlem River on the north, completely hampers extension. The inventive mind of the American was driven to some expedient, and the evolution of the high buildings was the result. The speaker desired, however, not to comment too much on American practice, but to describe European procedure. Mr. Riley.

This question had been approached from different standpoints. In the American tall building it is apprehended that the steel columns are

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* The discussion of this subject, for which no formal paper was presented, is continued from the August number of *Proceedings* in order that the views expressed may be brought before all members of the Society for further discussion.

† Superintending Architect of the London County Council.

Mr. Riley. the only portions of the structure which are carried to the foundations; they provide for the great resultant force of the building by carrying each story independently of the one above or below it. In the Building Acts in operation in London, Paris, Berlin and Vienna, it is laid down that the enclosing walls shall carry the structure, and, in the London Act of 1894, enclosing external walls are to be of the full thickness specified in the various schedules for at least half of their area.

The heights are also strictly limited in each of the cities named. In London, a building (not being a church or a chapel) must not be erected or subsequently increased to a greater height than 80 ft. (exclusive of two stories in the roof and of ornamental towers, turrets, or other architectural features or decorations), and, in a street laid out after August 7th, 1862, of less width than 50 ft., no new building shall be erected so that the height shall exceed the distance of the external wall from the opposite side of the street, without the consent of the London County Council. If the new street is over 50 ft. in width, the height may be carried to 80 ft., as if the building were in an old street; but if the street is, say, 49 ft. wide, the buildings upon it cannot exceed that height. The license allowed after 50 ft. width of street has been obtained may appear a little anomalous, but there is a very important further limit to height by providing for space in rear, and a governing angle.

The whole of the plot abutting on a new street, since 1894, must have a space of not less than 10 ft. unbuilt upon, and from the extreme boundary a line of 2 to 1 (or 63.5°) must be drawn, and no projections above that line must be erected except turrets, dormers and chimney stacks, and they must aggregate to limited portions of the width of the back frontage.

Some of the high buildings in New York must have very great cubical contents, but, under the London Building Act, the capacity is limited, *i. e.*, buildings for trade purposes of a larger cubical extent than 250 000 cu. ft. and not exceeding 450 000 cu. ft. must not go beyond 60 ft. in height. That, again, is a very notable restriction. The greater cubical contents can only be considered on the ground that a particular trade renders it absolutely necessary for the operations of that trade.

Houses for the working classes cannot be erected to a height exceeding the distance of the front, or nearest external wall of a building, from the opposite side of any street, unless the working-class dwelling is 20 ft. from the center of the street. In Vienna, the height of dwelling houses to the top of the cornice must generally not exceed 82 ft., and the floor of the highest story must not be more than 66 ft. In Paris, the heights of buildings are determined by the width of the street upon which they abut, the height being measured from the pavement perpendicularly up the face of the wall, including all construction and ornamentation, and must not exceed 40 ft. for public ways less than 26 ft. wide; 50 ft. for public ways 26 to 32½ ft. wide; 60 ft. for public ways 32½ to 60 ft. wide, and a maximum of 66-ft. height for public ways of 66 ft. and over. No building must exceed seven stories above the ground floor. Mr. Riley.

During a congress at the Paris Exhibition which the speaker attended he noted that one of the Continental speakers drew some very forcible illustrations as to the height permitted for buildings in London, but the horror with which he spoke of buildings 22 stories in height, which are permitted in New York City, was quite indescribable. These are very decided comments on the proposition before us, viz.: "What considerations should limit the height of buildings?" These are the European views, which, as a rule, are not hampered by the geographical conditions which obtain in lower New York City, but the implied criticisms are clear where expansion is more practicable, as in other American cities. The conditions in London are such that it is very undesirable to permit a greater height than 80 ft. The width of the old streets is small, there are comparatively few buildings built of incombustible materials, and the difficulty of attacking and controlling a fire in a narrow street with a limited head of water needs no demonstration.

The limited sunshine in London should be regarded as a factor in considering the heights of buildings in relation to its open spaces. Moreover, neighboring properties, which surely have vested interests in the light and air, should be duly considered. Lastly, the monumental character of some of the buildings in European cities, together with their association with the past history of their respective countries, would suffer more deplorably than they do even now if there were less consideration for the limitation of height. It appears clear, therefore, that it would be little short of a revolution in European cities to allow much further latitude in this respect.

The newest Building Code of New York City, which came into operation in October last, is an interesting document. In its provisions it is noticed that any hotel, lodging house, school, theater, jail, police station, hospital, asylum, institution for the care or treatment of persons, which exceeds 35 ft. in height, shall be built fire-proof, and every other building which exceeds 75 ft. shall be similarly constructed.

In a recent book* on fire-proof construction there are recorded some very interesting experiences on the behavior of high buildings in cases of fire. Illustrations are given of the Home Life Building, which the speaker did not remember to have seen, as it was probably erected since his last visit to New York. It is 192 ft. high, and was intended to be fire-proof, as all such high structures should be. A

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* "How to Build Fire-proof," by Francis C. Moore, New York, 1899.

Mr. Riley. building of 5 stories adjoining it took fire and burnt out every floor of the Home Life Building above its own height. The disaster appears to have resulted through a shallow court 20 ft. wide, used for lighting the higher building, drawing up the flames and communicating them from one window to another in the progress of the fire in the higher building. The court acted like a purposely constructed chimney in its destructive effect, though how a reputed fire-proof building burnt so freely and fiercely is not so apparent.

A court of this character could not be built in a new building in London. The limit of height of the parapet above the sill of any such window, if used for a habitable room, is twice the root of area of the court, and, in case of a room used as an office, would be limited to the general height permissible under the act, but in no case exceeding 80 ft.

The destruction of the Windsor Hotel made a great impression in this country. It was substantially built, and it was stated in some papers to have been fire-resisting, though that statement is inaccurate, as it was elicited that the floors were of open wood joists; some of the partitions were formed with "quarters" and the internal finishings were wainscoting. Such a building would hardly be classed as fire-resisting here; at any rate, it burnt with such furious rapidity that it was practically gutted within an hour and a half. There is no doubt that every such building should be as uninflammable as modern science can make it. The responsibility of dealing with life and property in such a structure is a burden no public official should be called upon to undertake. In spite of the most heroic efforts, and an expert corps of fearless and brave men, many lives were lost and the property totally destroyed. In the case of the Home Life Building the water pressure was 108 ft., but that failed to save the building up to that height.

The means of escape in case of fire are constantly engaging attention in London, and, at the present time, further powers in regard to the provisions of the Factory Act are now being sought from Parliament.

With the foregoing examples on record he would be a bold man who would recommend any serious increase in the height of buildings in London.

The next question for discussion is, "Do recent developments in construction, sanitation, intercommunication and economy of administration warrant the removal of all restrictions?"

Modern construction has materially improved the conditions and lessened the risks of escape in case of fire, but construction has little beneficial effect upon provisions which deal with width of streets, proximity to other buildings, and the open spaces about buildings. It needs little demonstration to show that restrictions of height of buildings secure the essentials of light and air which are required for proper sanitation, intercommunication and economy of administration. There is no doubt that the ingenuity of American engineers has made the tall building work with a facility which could hardly have been thought practicable a few years back. The Produce Exchange is remembered as the highest building in New York fifteen years ago, and in London would still be considered as a very tall building, although it is now overshadowed. Expansion in London is inevitable, and efforts must be made to improve the communication with outlying areas. The solution appears to be looked for in building in the suburbs where the inhabitants can enjoy fresh air, and simultaneously provide rapid and reliable means of transport to the central points. There is no apparent demand for increasing the height of buildings, and none for the removal of all restrictions; here it would be a calamity to adopt any such legislation. Mr. Riley.

It is difficult to approach these questions of comparison without being dogmatic, especially when convictions are strong, but the few remarks submitted will, it is hoped, be accepted in another spirit. The subject is one of great interest, and the developments have been carefully watched. Many experts in New York City are bitterly opposed to high buildings, and they freely condemn the result of recent years' work as a hideous disfigurement of the city. These views find many supporters here, but perhaps a better acquaintance with the conditions which made the problem might soften the criticisms.

American engineers and architects are hampered by no insurmountable traditions. When a city railway was a necessity it was not put in an "underground" tunnel, as in London, but erected on stilts, and it answers its purpose very well. When a luxurious ship was wanted for the Fall River traffic, the *Pilgrim* (probably out of date by this time) was evolved. Her beam engines and other features appeared antiquated twelve years ago, but a closer acquaintance with the conditions revealed that the type adopted had much to recommend it. The systematic method of American thinkers has been to first grasp the difficulties to be overcome, and then attempt to solve the problem in the most practical and common-sense way, unbiased by prejudices. If the tall building is not all that can be desired, it is another effort to solve a difficulty, and as experience is gained it may ultimately lead to some satisfactory result, but it is not a suitable form of structure for this part of the world.

Oscar J. Kirby, Esq.*—In high buildings of six and seven stories the speaker used corrugated steel doors with asbestos sheeting on either side, so as to cut off entirely one room from another, the grooves or corrugations being filled with ground clinker to give solidity to the doors. Bolts or rivets keep the faces of the doors compactly in posi- Mr. Kirby.

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* Engineer and Surveyor to the Batley Corporation.

Mr. Kirby. tion, the bolts being so arranged, where necessary, that they can be covered over with moulded asbestos to give the faces of the doors the appearance of wrought woodwork.

These doors, unlike the composite fire-proof tin-covered wooden doors, do not warp in a fire and break loose from the hinges or fastenings.

Mr. Parsons. H. DE B. PARSONS, M. Am. Soc. C. E.—Designing a tall building is a much more difficult problem than one would ordinarily conceive. "Fire-proof," "cage" and "skeleton" construction are three terms frequently used in connection with these buildings, which it would be well to define. By "skeleton" construction is meant that the outside walls of the building are self-sustaining, that is, they are carried up from the foundations as permanent walls. The interior of the building is supported upon a skeleton construction of steel or iron. By "cage" construction is meant that the building is supported *in toto* by the metal framework. The outside walls are mere curtain walls, and are supported themselves by the metal construction. Good examples of this construction have been shown by Mr. Purdy. The word "fire-proof" is used in a generic sense. It is impossible to conceive of any building which is intended to be inhabited and to contain the conveniences which the man of to-day demands, that could be built so as to be uninjured by fire. Fig. 1, Plate XXXVII, is a picture taken from the twentieth story of the American Surety Building, No. 100 Broadway, New York City, looking south, and gives a good impression of the height to which these structures tower. Wall Street, although only about 150 ft. distant from the building, is lost in the foreground. The Empire Building, No. 71 Broadway, which has been mentioned in this discussion, can be seen on the right in the picture. The low building shown on the left is that of the Union Trust Company, and was once considered tall, but it is now very much overshadowed by the next building beyond, namely, the Manhattan Life. The Bowling Green Building is seen in the distance and the Bay beyond. Looking down into the street below, one cannot refrain from imagining the difficulties which are encountered in the protection of these tall structures against the ravages of fire. Of all the elements which are tending to destroy these buildings, probably there is none so potent as fire. It will be interesting to show a few examples, picking out the worst cases rather than the best, in order to bring out the subject in the strongest light. In the first place, these buildings should only be constructed in the most fire-proof manner. It would not be good practice to build them according to the ordinary methods of construction, such methods as were mentioned in connection with the Windsor Hotel. Fig. 1, Plate XXXVIII, represents the Windsor Hotel, New York City, which was destroyed by fire on March 17th, 1899. The hotel, of which this picture only shows a part of the front,

PLATE XXXVII.
PAPERS AM. SOC. C. E.
OCTOBER, 1900.
PARSONS ON HIGH BUILDINGS.

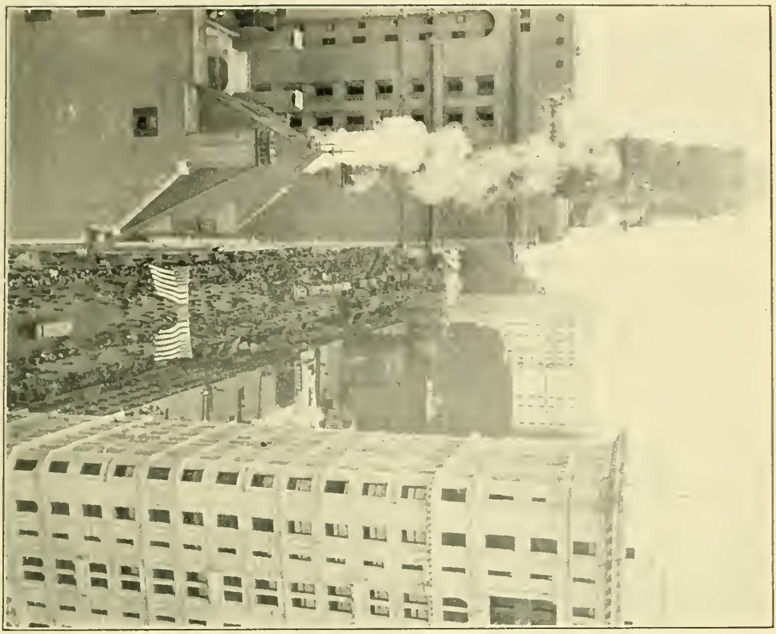

FIG. 1.—VIEW FROM TWENTIETH STORY OF AMERICAN SURETY BUILDING.

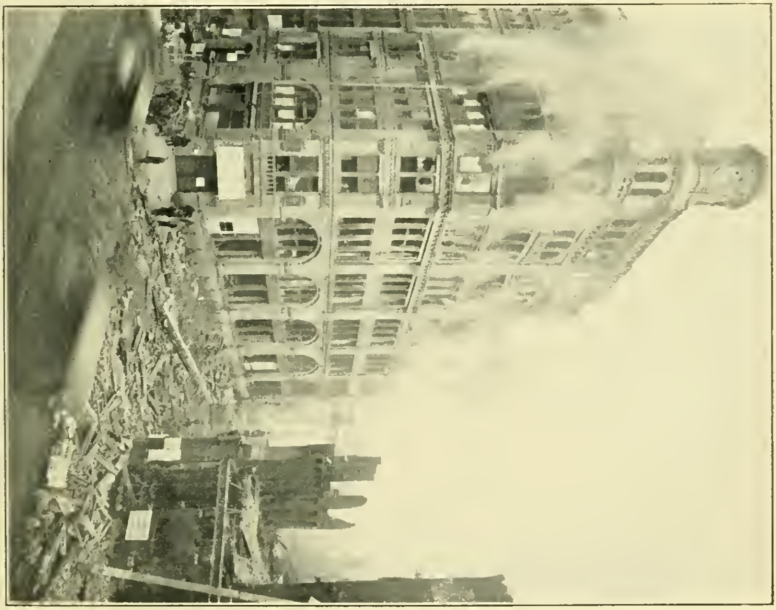

FIG. 2.—THE MANHATTAN SAVINGS INSTITUTION.

was 200 ft. in length and was built in the form of a shallow U, the Mr. Parsons. wings of which were 180 ft. in depth. In the rear of the hotel there was a court. The weakness of the building to resist fire was the design and the method of construction. At the center of the building and on the roof was located a large water tank. Through some error in the design, or through some change of plan, it is said that part of the building was supported from the roof by tie rods, the tie rods being carried by girders. The fire originated in the basement and spread with fearful rapidity throughout the building. It was known in New York as a dangerous building, owing to the wide corridors which ran from end to end on every floor, without any fire division walls whatever. This picture shows the building a few moments after the arrival of the engines. The fire was in the corridors behind the front rooms.

A few moments afterward, probably not more than two or three minutes, the photograph, Fig. 2, Plate XXXVIII, was taken. A tongue of flame had burned away the flag, and the building began to tumble in a central vertical section. The break occurred so quickly that the firemen had hardly time to get out of the way.

Almost immediately after the last picture, the conditions were as represented in Fig. 3, Plate XXXVIII. The tank had dropped from the top to the bottom, and that condition of affairs existed 35 minutes after the fire-alarm was given. Within a few moments afterward fire burst from almost every window simultaneously. Fig. 4, Plate XXXVIII, represents the condition about 45 minutes after the alarm was sounded, and was taken just previous to the fall of the wall. It was only 5 or 10 minutes after the south wall fell, that the north wall gave way and the hotel was completely ruined.

Many imagine that buildings constructed of iron, steel, cement, glass, slate, and tiles are fire-proof and indestructible, but such is not the case. In the Washburn & Moen Company's Quinsigamon Mill, which was built on the "cage" construction plan, the walls were merely curtain walls. The window frames and sashes were all iron and steel, and the only wood used was in the floors and roof. The floors were built on the slow-burning principle. The structure was not overloaded at the time. It was a building used for the manufacture of steel springs, which are not in themselves combustible, and the reason the fire spread so rapidly was probably due to the fact that in one part of the building there was an oil-tempering room, and the vapors from the oil baths had condensed on the under side of the floors.* The columns yielded within from 15 to 25 minutes after the fire started. Experiments which were made by the Committee on Fire-Proofing Tests agreed very closely with the facts recorded in this

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* Part of the ruins of this building are shown on Plate X, *Transactions*, Am. Soc. C. E., Vol. xxxix, June, 1898.

Mr. Parsons. fire. The plate to which reference is made illustrates very completely the destruction; and, when viewed from the standpoint of insurance, can it not be said with truth that iron and steel buildings will burn? Certainly, the destruction was complete.

The danger from fire in all large, tall buildings is greater from the hazard without than from any risk within. A fire, starting within a building which is of fire-proof construction, can be localized and put under control. But many buildings are subjected to an external hazard which is very great, owing to the large window areas and to the fact that there are windows on every floor, so that the fire may attack the building on all floors at once. Fig. 2, Plate XXXVII, shows the destruction of the Manhattan Savings Institution, New York City, during the winter of 1895 and 1896. It was at that time a modern building, and was well constructed so far as the materials were concerned. A building at the opposite side of the street caught fire; and the heat broke the glass of the windows, and was sufficient to warm the under-side of the girders which were exposed. They yielded; some, expanding, pushed out the walls, dropping the floor beams, and the building was a total wreck. Nothing was saved except some of the structure on the first or ground floor, and none of the fittings were in a condition to be used again.

On May 3d, 1897, there was a fire in Pittsburg, Pa., which originated in an old building containing a great mass of combustible material. Owing to the wind, it spread rapidly to a number of small buildings of similar construction, and attacked three modern buildings of the fire-proof kind. Reference may be made to the paper * by Corydon T. Purdy, M. Am. Soc. C. E., describing this fire. Fig. 2, Plate III, of that paper, shows part of the first floor of the Joseph Horne Dry Goods Store. It was a modern building, well constructed and well built, but in its construction there was in many points a total disregard of any fire hazard. The fire-proofing material stood well, and no fault could be found with it. The débris in the corner was caused by faulty design. On the roof there was a 5 000-gall. water tank, which was supported by unprotected iron girders and beams. Iron and steel, as shown in the Washburn Mill, will not stand unless protected. The result was that the tank fell from the roof to the basement. The damage done to the structure by the falling pieces was probably greater than the damage done by the fire. The well, which extended up through the building to give certain architectural effects and to let light to the lower floor, proved to be very hazardous. The fire was drawn up by the current of air and carried to the other floors as though the well were a flue.

Another view on the same floor of the same building is shown in Fig. 1, Plate IV, of Mr. Purdy's paper, and illustrates in a better

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* *Transactions*, Am. Soc. C. E., Vol. xxxix, p. 121.

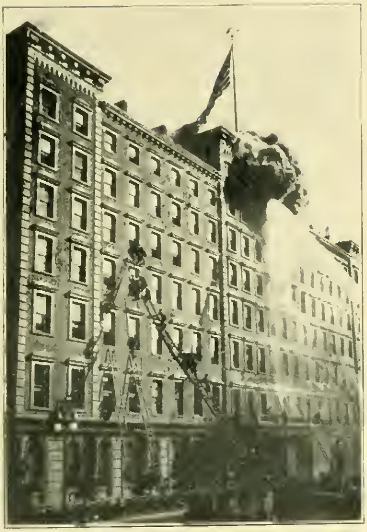

FIG. 1.—WINDSOR HOTEL FIRE.

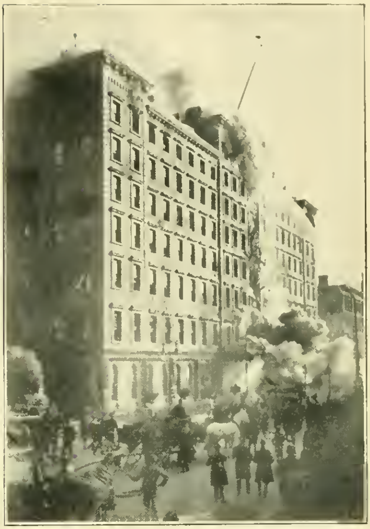

FIG. 2.—WINDSOR HOTEL FIRE.

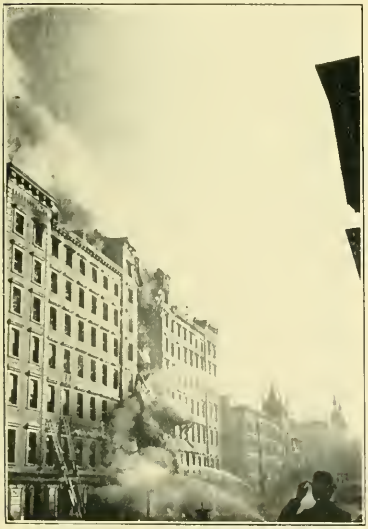

FIG. 3.—WINDSOR HOTEL FIRE.

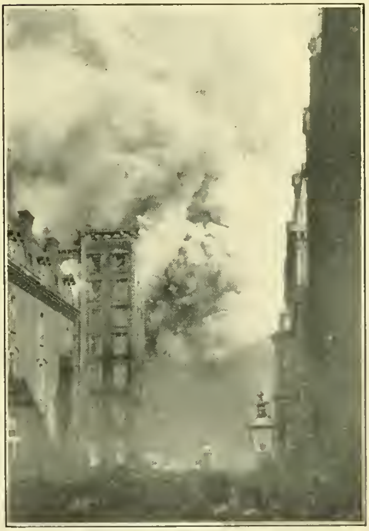

FIG. 4.—WINDSOR HOTEL FIRE.

Mr. Parsons.

manner the effect of the fire-proofing. All ornamentation is gone, but the fire-proof blocks were well preserved. Again referring to Mr. Purdy's paper, Fig. 1, Plate III, and Figs. 1 and 2, Plate V, show the exterior of the buildings after the fire. The damage in the Horne Office Building was very much less than in the Dry Goods Building, and was due to a better arrangement of fire-proof partitions. The location seems to be unfortunate, as the Dry Goods Store was rebuilt and has been burned a second time.

Mr. W. E. Riley has mentioned the Home Life Building, in New York City, as having been attacked by fire. Fig. 1, Plate XXXIX, shows this building before the fire. It is 16 stories high, 192 ft. to the roof, and 242 ft. to the top of the tower. The low building at the right was of ordinary construction, occupied as a clothing house, and caught fire. The tall building next to the Home Life Building is the Postal Telegraph Building. The wind was blowing at hurricane force, unfortunately, from the northeast, so that it blew against the side of the Home Life Building, which contained a court or light well. The flames were drawn into the well, which acted as a chimney, and, as all the windows were unprotected by shutters, the fire entered simultaneously every floor of the building above the 9th.

Fig. 2, Plate XXXIX, shows the building after the fire, and also the well or court just referred to. Of course, the small corner building was completely ruined. The destruction of the façade was complete from the 9th floor upward. Below that level, the building was practically intact and was used again by the tenants within a very short time after the fire. The contents of the 7th and 8th floors were badly damaged by water. The elevators and the staircase were located next to the light well, so that the flames on entering the building had free access to every floor.

Fig. 1, Plate XL, is typical of any room in the Home Life Building, above the 9th floor, after the fire. The fire-proofing stood the test and was found to be in such good condition, that most of it was used over again without any expense. The partition walls had large transom windows which were unprotected, and were fitted with ordinary glass set in wooden sashes. When the fire entered a room, it simply broke the glass and passed on to the next. Had these partitions been of a fire-stop character, all damage would probably have been confined to the rooms next to the building which originally caught fire.

Fig. 2, Plate XL, shows a wire-lathe and plaster partition which had been built on the wooden floor. The floor was laid on wooden sleepers, leaving an air space between the fire-proof arches and the wooden flooring. If this building had been constructed, as was originally intended, and as all such buildings should be, by filling this air space with ashes or concrete, and by resting all partitions directly on the arches, the probabilities are that the fire would not have damaged

Mr. Parsons. the partitions. As it was, when the wooden floor had been burned away, the partitions had no support and simply dropped.

The greatest damage to the steel frame-work is shown in Fig. 3, Plate XL, which represents a view of the front room on the 16th floor. The large girder had its lower chord well protected, but the upper chord projected above the floor level. This girder was covered with a flooring, raised in a sort of step toward the front wall. The wooden floor soon burned away, leaving the upper chord entirely exposed. It became red hot and buckled, as shown. The photograph does not illustrate very well the damage to the façade and window trim, owing to the strong light The missing fire-proofing blocks were removed from the column after the fire for the purpose of inspection, and this column, as well as all the others, was found to be in good condition. The blocks seen on the floor were knocked off by the firemen and by the City Building Department, and were not displaced by the fire itself. The heat in this room was very great, and, as can be seen, no plaster remained on the walls.

The marble front of the building, from the 9th story upward, was taken down and rebuilt. The Postal Telegraph Building was injured on the upper story by fire and only damaged by water on the floors below.

As a fire-stop, these tall buildings certainly acted marvelously well. It would be frightful to contemplate what might have happened during that gale of wind had these buildings not been there; but, of course, tall buildings are not intended as fire-stops.

In case of fire, any door or window opening is dangerous. The way to stop a fire from spreading is to confine it to the place where it originated. If circumstances necessitate a large floor area, then make such area a fire-proof floor and ceiling, cutting off all communication with the rest of the building. If possible, put the staircase in a tower-like structure on the outside, and give access to each floor by a bridge. Make all communication from one floor to another pass across the bridge, up or down the stairs, and back over another bridge to the next floor. It is best to subdivide large areas by fire-walls or by fire-proof partitions and have as few openings as possible. It is an impossibility not to have doors and windows in tall buildings, but such openings create a hazard. When the divisional walls are cut in numerous places, it is hard to conceive of a fire-proof building which could not be injured by fire. The danger from without is usually far greater than that from within.

In the United States, many prefer the "slow-burning" construction, and a wooden building made on this principle will outlast an ordinary steel building, unless the steel building is put up in the most approved manner with the members covered with the best fire-proofing, but this construction is not suitable for very high buildings. The

PLATE XXXIX
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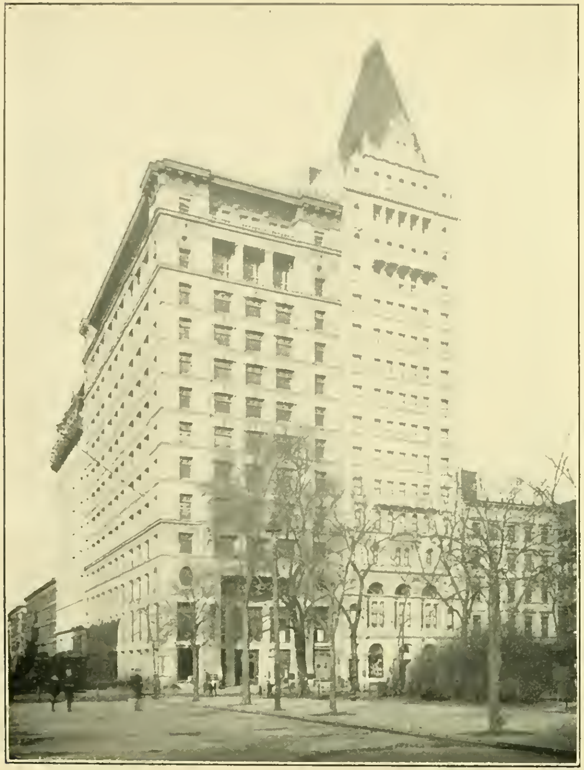

FIG. 1.—THE HOME LIFE BUILDING.

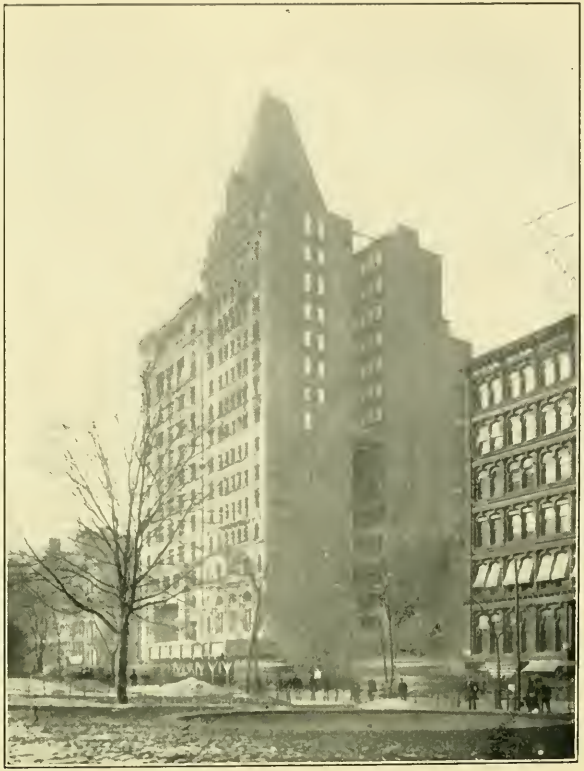

FIG. 2.—THE HOME LIFE BUILDING, AFTER THE FIRE.

"slow-burning" method simply consists in using large pieces of timber for posts and girders, so that the fire can char to a depth of 2 ins. or more without impairing the strength necessary to support the loads, and constructing the building so as to leave no air spaces. It takes a long time for fire to char a large stick to that depth, and by that time the fire department can come to the rescue. Mr. Parsons.

The lower floors of the Home Life Building were uninjured, because they were protected by the brick wall of the adjacent building which first caught fire. There is nothing better than an ordinary brick and cement wall, and such a wall protected the Home Life Building. The flames had to pass over its top, and then had an upward tendency from the draught of the well and elevator shaft, and the first windows which really got the attack of fire were on the level of the 9th floor. The 9th floor practically marks the limit of protection from the Fire Department in the street.

Tall buildings are now constructed with stand-pipes, which are large pipes 6 or 7 ins. in diameter, extending from the street level to the roof. At each floor there are arrangements whereby the fire hose of the building can be connected to the stand-pipe, and the City Fire Department engines connect with the bottom of the stand-pipe. The engines pump water into the stand-pipe and the firemen use the hose which is on each floor. In that way they save much valuable time as they do not have to carry up their own hose to great heights. In some tall buildings the elevators or lifts are in commission night and day for the purpose of fire protection, and in case of alarm the elevator is immediately sent to the lower floor to be ready to carry the hose or the firemen to the proper point.

The fire-door which has generally been found the most serviceable in the United States is that known as the Underwriter's door. It is simply a wooden door sheathed with tin. The door is often strengthened by being made of double plank laid diagonally. The coating is of ordinary tin well lapped. These doors will stand an enormous amount of heat before they fail. They are carried on a traveler overhead. The traveller is on an incline, and during working hours the doors are held back by a cord, a wire or a chain, in which there is a fusible link. The link operates the same as the sprinkler; at a certain temperature, which is quite low, it melts, and the door closes automatically. Many forms of patented fire doors have been used, but none with such universal success as the Underwriter's door.

R. J. Gifford Read, Assoc. M. Inst. C. E..—Some wonderful examples of the disastrous effects of fire on ironwork have been shown at this meeting, and attention specially called to the efficient protection which the fireproofing afforded. The speaker would be glad to know what material the fire-proofing was made of, whether it was of the nature of plaster, terra-cotta or brick. Mr. Read.

Mr. Read. He thought the views showed in a very clear and impressive manner the effects of fire on these high buildings.

With regard to the case where the fire originated in the eighth story and spread upward through the elevator shaft, he would like to ask how the people who were above escaped, and if, in tall building construction generally, there was any other method provided for escape than by the elevators.

In certain high buildings in London on which he had been engaged, provision for escape was made by outside balconies and staircases, or by outside galleries connecting one building with the next, or by escape ladders to the neighboring roofs, but these would scarcely apply in the very high American buildings.

Mr. Wallace. John F. Wallace, President, Am. Soc. C. E.—The cost of high buildings in Chicago has varied from about 30 to 40 cents per cubic foot, and the rental for office room above the ground floor has varied from $2 to $2.50 per square foot per annum. Of course, this cost of construction and rental received varies largely between buildings differently located. The rental generally includes janitor's service, elevator service, and sometimes heat and sometimes light. These figures may have been modified in the last two or three years.

High buildings had, not their origin, but their highest development in Chicago, and they were not constructed in order to get something larger than existed anywhere else in the country, as some people might have an idea, but from the circumstance that the business portion of Chicago is confined to a very small area. The Chicago River comes in from Lake Michigan for a short distance and then branches in a northwesterly and southwesterly direction, forming a Y. In the district south of the river, and between the river and the lake, what is known as the south side, the principal business of Chicago is carried on. The railway stations all have their termini within a comparatively small area, and the wholesale as well as all the retail houses are located in this district. The price of land per square foot, therefore, became very high on account of the congested business, and it was impossible for land owners to obtain for low buildings a rental which gave a reasonable return. In order to overcome this, and in order to receive an adequate return upon the assessed and market value of the land, they were forced to construct high buildings. In New York and other large cities of the same character it has not been a question of architectural beauty, nor a question of sanitation, but simply a business and commercial necessity. Therefore it may be interesting to our English brethren to have some idea of what those buildings cost and what rental they return. This would seem to be the key-note of the whole question.

In order that our English brethren may understand the situation in America it may be desirable to say that all American engineers do not

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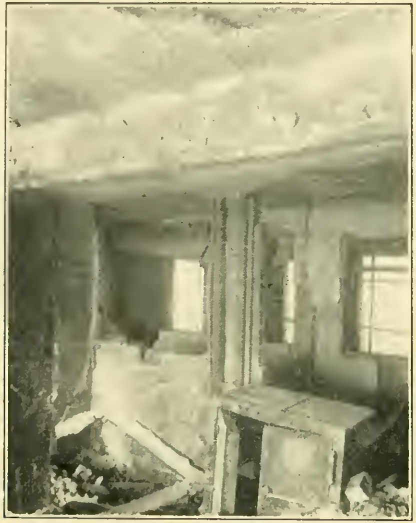

FIG. 1.—TYPICAL ROOM IN HOME LIFE BUILDING AFTER THE FIRE.

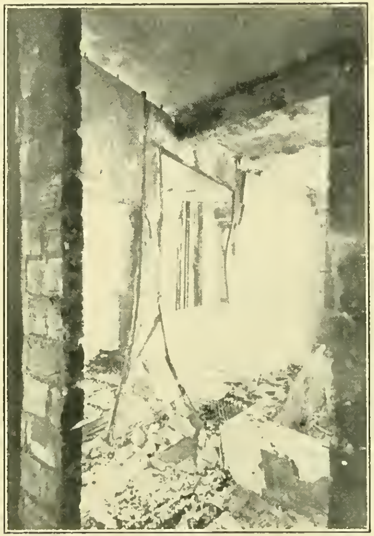

FIG. 2.—PARTITION OF WIRE-LATH AND PLASTER.

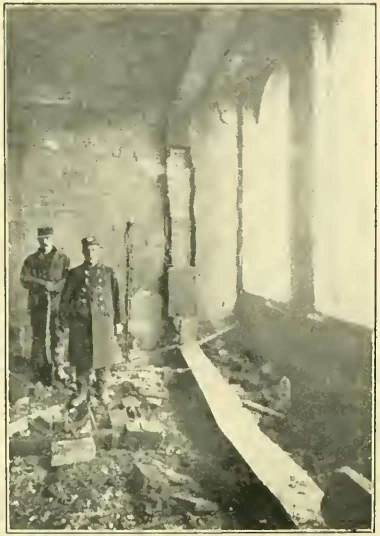

FIG. 3.—FRONT ROOM, SIXTEENTH FLOOR, HOME LIFE BUILDING.

Mr. Wallace.

favor the continuation of the construction of high buildings, even in large cities, and are very much divided in opinion on that subject.

Answering Mr. R. J. Gifford Read's questions: In the first case this fire-proofing is generally terra-cotta work. In the cage construction, in between the floor beams the floor is constructed of a series of terra-cotta blocks which are made with inclined joints and so formed that they make a flat arch. In order to make the blocks light they are made hollow; hollow tiling or terra-cotta work is also built around and envelops the columns, and in some cases it is joined by cement or is keyed around the columns. In the later constructions the fire-proofing is very carefully put around all the iron and the steel columns. Steel floor beams are not now looked upon as a fire-proof material. They simply furnish the ribs or the skeleton, as it might be called, on which the fire-proof construction is placed. At an earlier date concrete was used for these floors, and thin strips of wood were placed in it and the wooden floors nailed to these strips. In the later construction the floors are made of concrete on the top of this fire-proof terra-cotta work, and then small stones are put down in mosaic work and are then smoothed over. This makes the fire-proof floor, so that now, in a great many buildings, there is no wood except simply the doors and the window cases.

With reference to fire-escapes, in all American cities where high buildings are used, a certain number of fire escapes are now obligatory by city ordinances, and they are required to be constructed on the outside of the buildings, generally in connection with balconies and at the ends of the halls, and the number placed is in proportion to the size of the building. They are inspected periodically by the city authorities. The fire-proofing of buildings has received of late years serious consideration. When these buildings were first constructed it was supposed that the iron and steel work was fire-proof and would not yield so readily to the heat. The character of the occupancy of the buildings has a great deal to do with them. They are well adapted to office buildings in the congested portions of the city, but they are not adapted to retail business or dry good stores, or to any business where the contents are highly inflammable, except where they are constructed with fire walls and fire partitions and with isolated rooms. In Pittsburg, Pa., in a hotel of recent fire-proof construction a fire occurred in a suite of rooms, and two rooms with their furniture were entirely destroyed and burnt out. The occupant of the adjoining room did not know there was a fire until informed of it the next morning. That was due to the careful design of the building in reference to fire walls, terra-cotta work and the use of cement, concrete and mosaic floors, and the absence of transoms over the doors.

Mr. Parsons can give us some information regarding fire doors, but

Mr. Wallace. the speaker can answer with regard to some warehouses in the City of New Orleans, which have been constructed under his immediate control. One warehouse was 1 200 ft. long and 100 ft. wide, for the storage of cotton, cotton-seed oil, and products of that kind, which are highly inflammable. That building was constructed with brick foundations up to the level of the floor and then filled in with earth upon which a concrete floor was constructed, dividing it up into sections. Very narrow openings were left between the different sections, and were protected from each other by what you might call twin doors, with an air space between them. It is not permitted to pile any material within a certain distance of these doors.

Mr. Hunt. ROBERT W. HUNT, M. Am. Soc. C. E.—Office rents vary in the different buildings and cities. The location controls the price just as it does under other circumstances. The speaker, ever since he has been in Chicago, has had offices in one of the first fire-proof high buildings built in that city. From the historical fact that the ground on which this building now stands was formerly occupied by such rattle-trap affairs that it was known, the city over, as the "Rookery," it was called "The Rookery" by the capitalists who secured the land from the city on a ground rent of 99 years. It is a building which will compare very favorably with any in the United States, although it was one of the first high office buildings. It is recognized from its location, history and associations as probably the most desirable building in Chicago, and as it can only hold a certain number of people, tenants have to pay quite the high figure named by Mr. Wallace, which is probably the highest rent charged by any of the buildings in the city. There are 3 200 people in the building. Its cost was about $1 800 000, and from its inception to the present time it has never paid its owners less than 12% on their investment, which makes it rather a profitable one for them. There are ten passenger elevators and one freight elevator, and the check which has been kept upon the number of people riding in them at different times shows that as many as 22 000 and 23 000 per day have been carried. Of course, that number does not represent different individuals, but the number of passengers carried. Every one living above the first story probably takes four rides a day, in addition to which there are business visits between the offices, and people coming to see the occupants.

"The Rookery" is a town within itself. It has in the basement its own power plant, its own pumps, its own heating arrangements, its own electrical service. It has its own carpenters, its own painters, its own plumbers, and every mechanic necessary is employed in the building permanently. They start from the roof and work down to the ground as regularly as the years roll on. By the time they reach the ground itself or the basement, the top of the building is in a condition to need their work once more, and they repeat the process, so that the building, after its 12 or 13 years of life, is just as good as it was the day it was built. I am under the impression that the rate of rent my firm pays for New York offices in the Empire Building, at 71 Broadway, which is one of the newest buildings, is a little higher than that paid in Chicago. Mr. Hunt.

Mr. Sloan. Maurice M. Sloan, Esq. (by letter).—The public good, or the common welfare of the community, is the only consideration that should regulate the height of buildings, and the law of commonweal, though sometimes slow, is ever present and a governor of all things human.

This is undoubtedly the legal aspect of the discussion, for it places the rights of the owner, on the one hand, to build as he chooses, over and against the rights of the people, on the other, to restrict as they deem advisable.

The restrictions placed upon the height of buildings by a community should be confined entirely to such as they have a right to impose. That public prejudice and æsthetic considerations should interfere with the owner's individual right to build as high as he pleases is unreasonable and absurd. Public prejudice is undoubtedly a strong factor, but the world would have remained in an exceedingly primitive state if it had always obeyed the admonitions of this fickle and somewhat unreasonable goddess, while æstheticism, with its principles and doctrines, so often results in mere whimsicality or grotesqueness that it cannot be taken as an imitable law, and is not worthy of consideration in so vital a question as that under discussion.

Where the height of a building, however, affects the safety of either the individual or the community, and jeopardizes life and health, or even stagnates commercial operations by congesting the traffic in the street upon which it is located, restrictions should be fixed, and too much care cannot be exercised in determining what should be the limitation.

That a building may be constructed to any height with perfect safety is a proposition generally accepted, though many conjectures arise as to the terrible havoc and loss of life that would be caused should earthquakes of great severity, or cyclonic storms of unusual violence, devastate the modern city of skyscrapers. These conditions are, however, of such a cataclysmic nature as to entirely preclude them from an argument for or against high buildings.

From a hygienic point of view there is little doubt that tall buildings are a menace to the health and happiness of a community. Sunlight is a natural disinfectant, and should be allowed to penetrate to every city street, flooding it at least for a few hours each day with its purifying rays. The fulfillment of this seemingly unimportant condition is really of vital moment, and can illy afford to be neglected

Mr. Sloan in a great city teeming with a population susceptible to decimation by contagious and infectious diseases.

It would almost seem that this consideration was of sufficient importance alone to regulate the height of buildings, and would give a basis to work from, at least in temperate climates, that would insure light and airy streets, free from the miasma which is so typical of the narrow passageways between high buildings in a city. Such a basis of determination would not only satisfy the exacting requirements of the sanitary engineer, but would in many cases meet the demands of the æsthetician.

In considering the necessity for providing sunny and healthful streets, take for example the conditions as they exist in New York. This city is in latitude 40° 43′ N., and the sun's declination is 23° S. in midwinter, that is, on the 22d of December. The altitude of the sun at noon is found by the formula:

$$\text{Alt.} = 90^\circ - (\text{Lat.} + \text{Decl.}),$$

and equals 26° 17′, giving a zenith distance of 63° 43′. Assuming a building 100 ft. high, located on a street extending east and west and letting the width of the street represent the tangent, and the height of the building the radius of the angle 63° 43′, the width of the street necessary in order that the sunlight may penetrate to the foot of the opposite side walls would be 202 ft. Such a street would be entirely too wide and pleasant for the economist and utilitarian, but, after all, would it not make a city of such healthfulness and beauty as to be the envy of the world.

While it is true that the sunlight could never, at least in winter, penetrate to the entire street, the reflected light from the opposite wall would be all that was necessary to promote a healthful atmosphere and light buildings and streets. The width of the street, figured on this basis, would also take care of any possible traffic brought about by the usual commercial transactions. It is universally understood, and conclusively proven, that recent developments in sanitation, intercommunication and economy of administration, remove all restrictions relative to the height of buildings. There are, however, limitations imposed by economical construction which will prevent the height of buildings from exceeding that already attained at the present time.

One of the factors which will tend to limit the height of buildings is due to the fact that as the distance from the foundation to a story increases, the investment required to construct that story is likewise increased, and as the returns on the investment are not subject to such an increase, there is a limit beyond which it is unprofitable to go. Such a condition arises from the fact that the increased sectional area required in the columns to support a given floor extends not only

Mr. Sloan. throughout the length of the columns in the tier below, but throughout the entire distance from the floor in question to the foundations. Similar considerations apply as well to the wind bracing, especially where diagonal bracing is used, and where the building is regarded as a cantilever beam supported at the foundation, for the wind bracing at any floor must be proportioned to sustain the increment of stress from all the floors above.

It is such conditions as these that have made the growth of the ocean liner and the locomotive slow, and kept the span of bridges within reason, and will likewise prevent the design and construction of buildings of greater height than those at present erected.

Vol. XXVI. OCTOBER, 1900. No. 8.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS AND DISCUSSIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

FILTRATION OF WATER FOR PUBLIC USE.

An informal Discussion at the Annual Convention, July 3d and 5th, 1900.*

SUBJECT FOR DISCUSSION.

"The several Processes now used for the Removal of Objectionable Matter; their Comparative Sanitary Effect, Cost and Reliability."

By Messrs. NICHOLAS SIMIN and ANDREW JOHNSTON.

Mr. Simin. NICHOLAS SIMIN, Esq.† (by letter).—Moscow will soon have to decide upon the method of filtering daily 45 000 000 U. S. galls. of river water, the quantity necessary for its municipal water supply. This circumstance was the cause of the writer's journey from Moscow to the United States of America in the autumn of 1897, when the so called "American method of water purification" or "the rapid sand filtration with coagulation" had just begun to receive a scientific sanction in America.

The purification of water by subsidence and with the aid of coagulation by alum has been practiced since ancient times, and its good results in making the most turbid waters clear as crystal are well known. The modern "American method of water purification" is but an improvement of the older one by changing the process from a slow to a rapid one.

During the first ten years of its development in the United States it was not under scientific control, and was advocated merely on commercial grounds. The great advantage, however, of a method of rapid filtration with coagulation caused several series of well-arranged scientific investigations to be made, and their results led to material improvements. Mr. Simin.

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* The discussion of this subject, on which no formal paper was presented, is continued from the August and September numbers of *Proceedings*.

† Chief Engineer of Moscow Water Works.

The first of these investigations was made in the year 1893 by Edmund B. Weston, M. Am. Soc. C. E., in the City of Providence, R. I. In 1896 and 1897 more extensive investigations were undertaken in Louisville, through the initiative of Charles Hermany, M. Am. Soc. C. E., and directed by G. W. Fuller, Assoc. M. Am. Soc. C. E., who gave to the science of water purification a great literary work without equal. At the same time independent scientific tests of mechanical filters were made in Lorain, O., by the State Board of Health, under the direction of Allen Hazen, M. Am. Soc. C. E.

At the close of his work in Louisville in 1898, Mr. Fuller made further studies in Cincinnati, O., where the importance of subsidence, with and without coagulation before filtration, was especially well demonstrated. In 1897 the City of Pittsburg, Pa., made parallel experiments with slow and rapid filters, under the general direction of Mr. Hazen. In 1899 Weston again experimented in East Providence, R. I., and in Norfolk, Va., and in March, 1900, Col. Miller terminated a comparative test of slow and rapid filters in Washington, D. C., resulting in a recommendation to adopt the rapid method of water purification for 60 000 000 galls. daily.

All these scientific investigations combine to prove that "rapid or mechanical filters" are able to give good results; and although Mr. Hazen recommended slow filters for Pittsburg, Pa., this did not prevent him from stating that the rapid filters were also able to purify water, and to remove its coloring matter to a greater extent than possible with slow sand filters.

At the time, when the writer was still under the inspiration of his inspection of mechanical filter plants in the United States, when he was familiar only with the work of Weston, in Providence, and could have but a superficial idea of Mr. Fuller's work in Louisville, he expressed his opinion* that no obstacle would be able to stop the spread of the "American rapid method of water purification." Now, since all the above-mentioned scientific investigations are in public possession, the writer cannot do otherwise than reaffirm that opinion.

The writer now wishes to glance at the matter from a Russian standpoint.

The method of water purification with slow filters has been used in Europe about seventy years, and it has proven that good results can be obtained by it. At the same time they are not always obtained. In Russia not a single case of slow sand filters can be considered as being

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* *The Engineering News*, March 19; July 23, 1898.
The Engineering Record, March 24; July 21, 1898.
Fire and Water, Vol. xxiii, No. 12.

Mr. Simin. wholly successful. The best filters of this kind were built in Warsaw by the talented Mr. Lindley, and they left the water turbid during the session of the second Convention of the Russian Water Works Association, held in 1895. The slow sand filters in Odessa, also very well constructed by English engineers, work at the rate of only 3 ins. per hour, and yet cases of unsatisfactory effluent occur often. In St. Petersburg the slow sand filters work with too great a velocity, and their average bacterial efficiency does not amount to 60 per cent. In several other Russian cities slow sand filters are also made to work at too great velocities, on account of their insufficient size, and, therefore, give bad results. The writer believes that such cases of lack of success occur also in Western Europe, where English slow filters are used at many city water works.

American mechanical filters are almost unknown at municipal water works in Europe, and many superstitions exist regarding them. Systematic scientific investigations of the "American method of filtration with coagulation and sedimentation" have not as yet been made here. The investigations now undertaken by the Moscow municipality, after the example of Louisville and Pittsburg, should, therefore, be considered as the first made in Europe.

The water is taken from the Moscow River, within the city, where it is considerably polluted by sewage and factory refuse, and has a very changeable character.* Many special investigations, already made at the Moscow experimental filter plant, have cleared the subject, and the results in general agree with those obtained in America. Last March and April, when the stage of the river was high, and when the water was very turbid, the mechanical "Jewell" gravity filter moved 97 to 99.8% of the bacteria, and the filtered water during the whole time was quite clear. Sulphate of alumina, in quantities from 4 to 6 grains per gallon, was used as the coagulant, such large quantities being necessary to obtain satisfactory bacterial results.

Although these investigations are intended to extend over one whole year, they cannot be considered as final, because they do not indicate the results which would be obtained if the water is taken at the proposed new intake for the city water supply, to be located 30 miles above the city. The water there contains but about 400 bacteria per cubic centimeter, and therefore will require much less coagulant for its purification. On that account it is proposed to continue the investigations at the place where the water for the future supply will actually be taken, and to make parallel experiments with mechanical and slow sand filters.

If the experiments should be limited to those now being made in Moscow, the writer is not sure that they would secure the adoption of mechanical filters for the Moscow water supply. The citizens are not Mr. Simin. yet accustomed to the idea that it is possible to dispense with slow sand filters for water purification. If the writer continues the experiments for another year, he will have more data and believes it will then be easier to remove the prejudice against the American method of water purification.

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* The Moscow River water, at the point where it is taken to the filters, contains from 25 000 to 2 500 000 bacteria per cubic centimeter, on the average, about 200 000.

The writer feels certain in his conclusion that the most reliable, the most comfortable, the easiest and cheapest method, and the one best adapted to control scientifically the purification of the Moscow city water supply, is the American method of rapid filtration with coagulation of organic matter.

The reasons are as follows: In the daily practice of water purification one should certainly give preference to a plant, the sanitary operation of which can be more easily subjected to scientific control. Such a control is more readily obtained by the American rapid filters than by the English filters for the following reasons:

1. If the normal operation of an American plant is somewhat disturbed, it is very easy to restore it by washing and coagulation. After a ten-minute washing it is possible in three minutes to receive a good effluent, while the effluent of the English slow filters can not be quite satisfactory until 3 to 5 days after cleaning, during which time the filtered water must be allowed to run to waste. In case the effluent suddenly appears turbid, the filtered water must also run to waste until it clears itself. In this sense it is not possible to control a slow sand filter.

2. In countries having severe winters, the American method of water purification costs much less than the method requiring covered slow sand filters. (The cost of filtration by means of rapid filters and of open slow filters is about the same.)

3. By the American method it is possible, not only to make the water clear and to remove the bacteria from it, but also to remove the color caused by vegetable pigments and other organic matter. Slow filtration removes such coloring matter to a much smaller extent, which is an important and insurmountable defect of that system.

4. In the case of American filters an increase in the rate of filtration does not cause such a noticeable depreciation in the quality of the effluent, as in the case of English filters. At the Moscow experimental plant a satisfactory effluent is obtained with a rate of 150 ins. per hour, and it remains practically the same up to a rate of 250 ins. per hour.

5. Occupying over fifty times as much horizontal area as American filters of the same capacity, the English filters meet with serious difficulties when there are no suitable pieces of ground upon which to locate them.

6. The method of cleaning the English filters is complicated and inconvenient. The sand has to be removed by hand and periodically

Mr. Simin. restored by hand. The washing of the sand by machines presents difficulties during freezing weather. The washing of mechanical filters is easy and quick, and obviates taking the sand out of the filters. The rapidity of washing obviates also the large reserve filtering areas of the slow method.

7. The existing English slow filters make it too easy to increase the quantity of filtered water, and thus to avoid the erection of new filters. To do this it is only necessary to increase the velocity or rate of filtration and to dispense with the wasting of the first effluent. Such a practice, however, is detrimental to the quality of the effluent water. With the use of mechanical filters an increase of the quantity of the filtered water is much more easily and cheaply obtained, by adding a small supplementary rapid filter than a large English filter. Nor is it necessary to waste such great quantities of the first effluent. Furthermore, the increase of velocity of filtration does not affect the quality of the effluent to the same extent as in the case of English filters.

8. In many cases American filters offer a possibility of uniting the process of filtration with that of softening the water or of freeing it from iron. With the English filters this double effect is not attainable.

The greatest hindrance to the adoption of the American method is the fact that it requires a coagulation, that is to say, the introduction of chemicals into the water. It is often said that the public is afraid of the sanitary effects of a chemical treatment of the water which it is obliged to drink. The writer sees no justification in such fears. Mankind often employs chemical processes for various purposes, and to a great extent, so that the micro-chemical process of coagulation, when the water is subsequently to be filtered, must not be regarded as anything out of the way. The writer thinks that the spread of the American method at city water works, when subjected to a good sanitary control, may be considered even as a sign of an increasing public culture and public reliance upon a triumphant science.

During the last few years America has made many scientific and practical investigations of rapid water purification. Not a single one of them has undermined its reputation, on the contrary, all of them have strengthened it.

America has investigated also the English or slow method of filtration, and has proved that it also may give good results.

The science of water purification is much indebted to America and to its literature for the studies made of both the English and American methods. Europe did not do as much for the English method alone as America did for both.

The writer thinks, however, that the American investigations on slow filtration cannot wholly serve as a basis, as regards its daily prac-

Mr. Simin.

tical working, because during the investigations the filters are always placed in a more favorable condition than that which they are likely to get in practice. Only when made on large filter plants in daily use, and when free from idealization, are such experiments able to show clearly all the merits and defects in their true light. Our present water works literature hardly yet contains a record of any such investigations as regards English filters. The writer feels sure that such investigations, if systematic and thorough, would clear the way for the further spread of the American method. Therefore, although insisting on the use of this method for purifying the new Moscow water supply, the writer recommended that one filter with a daily capacity of 500 000 vedro (1 625 000 U. S. galls.) should be arranged according to the English method with all its improvements, and that such a filter should work under the best practicable conditions simultaneously with the mechanical filters.

If the writer succeeds in having an American filter plant of 45 000 000 U. S. galls. daily capacity, adopted for the Moscow water supply, he would take care that the English filter plant, which it is proposed to build for 1 625 000 galls. per 24 hours, should remain for permanent use, so that investigations of both systems could be made under permanent scientific control and on an equal footing.

The investigations made in the United States of America have thrown much light upon the method of rapid water purification. Let us hope that a similar light may be thrown upon the English method of slow filtration, which almost exclusively for 70 years has served in European water works practice.

Mr. Johnston.

ANDREW JOHNSTON, M. Inst. C. E.—The discussion upon this subject appears to have been selected at a most appropriate time when it is remembered how large a percentage of our losses in South Africa is due to diseases very greatly attributable to contaminated water.

For some time the speaker has been conducting experiments with the water of the River Ouse, in Yorkshire, and for that purpose has had constructed two filters each having an area of 4½ sq. yds. One filter is composed of sand and gravel only, and the other has a layer of Polarite 1 ft. 9 ins. thick between sand and gravel, each filter having a total depth of 5 ft.

The water treated contains in storm time much fine clayey matter, and has a strong yellow or peaty color, due mainly to organic contamination.

The sand filter slightly reduced the color, while the Polarite completely removed it. Both filters, of course, removed all suspended matter as well as reduced the bacteria to one per cubic centimeter.

The following are the analytical results in parts per 100 000 of the important constituents.

Mr. Johnston.

	Water from subsiding reservoir.	Water from sand filter.	Water from Polarite filter.
Free ammonia	0.01672	0.0084	Trace only.
Albuminoid ammonia	0.0194	0.0096	0.0078
Oxygen absorbed in 4 hours	0.214	0.095	0.032
Bacteria	312	1	1

The sand filter was working at the rate of 480 galls. per square yard per 24 hours, and the Polarite filter at the rate of 2 444 galls. per square yard per 24 hours, or, in other words, the Polarite filter was doing 500% more work than the sand filter, and giving a higher degree of purification.

Comparing the foregoing results with those given by Mr. Lindley, in his admirable description of his elaborate system at Warsaw, it is found that the rate of filtration, in the speaker's experiments, as compared with his, is as follows:

The speaker's sand filter was working at the rate of 2 607 liters per meter per 24 hours, and the Polarite filter was working at the rate of 13 273 liters per meter per 24 hours, as against the Warsaw maximum rate of 87 liters per meter. It should be stated, however, that the speaker first causes the water for the Polarite filters to pass through a mechanical Polarite clarifier, working at the rate of 27 000 galls. per square yard per 24 hours.

No coagulant is used, as it is against English practice to use any chemicals in water for drinking purposes.

Although it may be argued, and to some extent truly, that to compare the results of experiments extending over a few months with those obtained by Mr. Lindley in experiments lasting for a number of years is not fair, yet the speaker does not think such an argument will affect this subject, because he is able to state, from the experience of other engineers, that equally good results are obtained at water-works where Polarite has been used for many years. At the West Hants Water-works, Christchurch (England), the supply is taken direct from the River Avon, is first passed through Polarite automatic clarifiers, which remove the suspended matter, and is then, by simple arrangements, sprayed upon Polarite filters. One feature of the method at Christchurch is that the use of the clarifier enables subsidence reservoirs to be dispensed with, thus effecting a great saving in cost.

The following is an extract from the Government Official Report of Dr. F. St. George Mivart, to the English Local Government Board, on the "Sanitary Circumstances and Administration of the Borough of Christchurch, South Hants," and shows the pollution to which the River Avon is subject above the intake of the water-works:

Mr. Johnston.

"The River Avon, from which the supply is now wholly derived, rises in Wiltshire, in the neighborhood of Devizes. I do not propose here to deal with pollutions which enter it in the earlier part of its course. On its banks, in the vicinity of Christchurch, are a number of considerable aggregations of population, most of which, as I understand, get rid of their sewage by discharging it more or less directly to the river a few miles above the intake. My inspection of the river did not extend beyond that portion of it in the immediate neighborhood of the Borough, and hereabouts I noticed that pollution is possible, by reason of pig-keeping upon a large scale, carried on close to the river, about a quarter of a mile above the intake, and from the keeping of animals and poultry by the tenant of the mill at the site of the water-works."

Notwithstanding the fact that the River Avon cannot be looked upon as an ideal supply, yet, so successful is the filtration process adopted that the water as it issues from the Polarite filter is of excellent quality, and is shown by the following analyses to be brought into a condition equal to that of the purest well waters of this country.

	KENT DEEP WELL. ANALYSIS BY DR. P. FRANKLAND, DECEMBER, 1898.	WEST HANTS, FILTERED. ANALYSIS BY DR. A. ANGELL, DECEMBER, 1898.
	Grains per gallon.	
Free ammonia	Not any.	Not any.
Albuminoid ammonia	0.005	0.006
Nitrogen as nitrates and nitrites	0.311	0.191
Chlorine	1.75	1.05
Total solids dried at 212° Fahr	28.98	20.44
Total hardness	18.6°	11.0°
Permanent hardness	4.8	3.1
Removable by boiling	13.8	7.9

The Polarite filters at Christchurch were laid down in 1895, and continue to work as satisfactorily now as when first put into operation.

At Hastings* (England), Polarite filters have been used for ten years on the public water supply, and the following are analyses and report by the Official Chemist on two samples of Hastings water purified by Polarite, and taken from two different filtering stations:

" Appearance	Clear.	Clear.
Color	Colorless.	Colorless.
Hardness before boiling	11.3° Clark.	11.7° Clark.
	GRAINS PER GALLON.	
	No. 1 Sample.	No. 2 Sample.
Oxygen absorbed from permanganate	.008	.008
Chlorine	5.32	7.14
Nitric acid	.21	.12
Ammonia	.0019	.0000
Albuminoid ammonia	.0000	.0000."

* Population supplied with water, about 80 000.

Mr. Johnston. "These waters are, chemically speaking, of great organic purity."

At Reading * (England), the whole of the public water supply is purified by Polarite, and the following chemical analyses and bacteriological results, extracted from a report to the Water-Works Committee, show the effect of this method of filtration.

"The results of the analysis are expressed in parts per 100 000, and are as follows:

Chlorine	1.30
Nitrous acid	0.00
Nitric acid (N_2O_5)	0.46
Phosphoric acid	Very faint trace.
Sulphuric acid (SO_3)	0.03
Total solids	23.92
Free ammonia	0.0000
Albuminoid ammonia	0.0092
Oxygen absorbed from permanganate at 80° in ¼ hour.	0.0441
" " " " " " 4 hours	0.0895
Temporary hardness	15.2
Permanent hardness	4.6
Total hardness	19.8
Lead and copper	Absent.
Odor at 100° Fahr	None.
Color and appearance in 2-ft. tube	Pale, green, clear.
Deposit	Slight. Microscopical examination satisfactory.

"Number of colonies of micro-organisms in the river water, 1 200.

"Number of colonies of micro-organisms in the filtered water, 8.

"The micro-organisms in both the river and the filtered water were considerably less numerous than they were last month, and over 99% of those existing in the former had been removed by filtration.

"The results of the chemical and bacteriological analyses are satisfactory, and show that the filters were working well."

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* Population supplied with water, about 80 000.

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PAPERS AND DISCUSSIONS.

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THE NINETY-SIXTH STREET POWER STATION OF THE METROPOLITAN STREET RAILWAY COMPANY, OF NEW YORK CITY.

Discussion.*

By Messrs. F. L. AVERILL, ALBERT CARR, W. A. LOW, WERNER BOECKLIN, Jr., and J. D. KENT.

F. L. AVERILL, Assoc. M. Am. Soc. C. E. (by letter).—The design of coal pockets for steam plants has, within a few years, received considerable attention, both as to the stresses induced in the framing and in the details of construction. It is to be hoped that the author will incorporate further details of this notable pocket in the final publication. Mr. Averill.

With the present knowledge of the subject, it is surprising to note how recently large steel pockets have been erected without precautions being taken to avoid the certain corrosion. There have even been cases where some of the principal members of the framing have been exposed to contact with the coal.

The disastrous failure of a large pocket in Paterson, N. J., in 1897, created a discussion, among engineers and in the technical papers, of much practical value, which has borne fruit in the more recently designed pockets.

The maximum loading and the prevention of corrosion are now well

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* This discussion (of the paper by L. G. Montony, Assoc. M. Am. Soc. C. E., printed in *Proceedings* for August) is printed in *Proceedings* in order that the views expressed may be brought before all members of the Society for further discussion.

Communications on this subject received prior to October 26th, 1900, will be printed in a later number of *Proceedings*, and subsequently the whole discussion will be published in *Transactions*.

Mr. Carr. defined in good practice. There is another point sometimes lost sight of in the design of such pockets: namely, avoiding "dead spaces" between the chutes, where coal can remain lodged. It is asserted by men of experience that any mass of bituminous coal left stationary is certain, sooner or later, to ignite by spontaneous combustion. The writer knows of one large storage pocket where men are sometimes put in to move coal by hand to guard against danger from fire.

The writer recently had to design a coal pocket for the United States Bureau of Engraving and Printing, at Washington, D. C., incident to extension and improvements in the steam plant. There were limiting conditions, partly architectural, so that an ideal arrangement of coal-handling apparatus was impossible. The scheme of framing and the details of construction, however, may be of interest.

The bottom part of the pocket was made in the shape of several inverted pyramids, thus avoiding any spaces for the lodgment of coal, and at the same time permitting the use of deep lattice girders between the several pyramids. These girders give stiff bracing, and support a large proportion of the load.

Expanded metal, wired to angles, was used to prevent the cracking of the concrete.

For the vertical sides of the pocket, brick filling was used between the beams, as one side of the pocket formed the outside wall of the building.

Since reading Mr. Montony's paper the writer has determined to recommend waterproofing in addition to the cement and concrete protection for the pocket at the Bureau of Engraving and Printing.

The writer was ably as isted in the foregoing work by Kort Berle, Assoc. M. Am. Soc. C. E., who made most of the calculations and worked out the details.

Mr. Carr. Albert Carr, Assoc. M. Am. Soc. C. E.—In regard to the construction of the foundation work there are some minor points which the author might have put a little differently if he had consulted with some one having to do with the execution of the work.

The only point of real importance, perhaps, is the statement in regard to cement and concrete. The author states that "the concrete used was a mixture of one part cement, two parts sand and four parts broken stone, and the cost $5 or $4.50 per cubic yard, according to whether Portland or Rosendale cement was used." So far as the speaker is aware or has any record, not a barrel of Rosendale cement was used in this work, and no concrete was mixed in the proportions quoted.

The concrete under the chimney was nearly all mixed in the proportions, 1 cement, 3 sand and 5 broken stone. The concrete outside the chimney was nearly all mixed in the proportion of 1 part cement, 4 parts sand and 4 parts $\frac{3}{4}$-in. broken stone and 4 parts $1\frac{1}{2}$-in. stone.

Mr. Carr.

The cost quoted is substantially correct, but the difference in cost is due to the difference in the proportions of material used and not to difference in cement as stated. Also, a small part of the difference in cost is due to the fact that part of the concrete was machine mixed and part hand mixed.

The author states that the excavation for the building was sheet-piled all around. The excavation was sheeted on three sides complete, and on the fourth side only far enough to cross the cribs which are mentioned. It is an interesting feature of the sheet-piling that the side of the excavation left unsheeted was towards the East River, which was about 60 ft. distant.

The sheet-piling crossing the cribs mentioned consisted only of a single line 10 ins. x 12 ins. tongue-and-grooved timber and was not puddled. Two lines of sheet-piling were driven across the crib at the north side of the excavation, but the driving of the second line was due to a change in location of the east wall of the building, and not because a single dam was not entirely successful in holding back the water.

Mr. Low has amplified Mr. Montony's description of the sheet-piling around the chimney foundation. The speaker is responsible for the plan of holding back the sheet-piling by tie rods instead of using the ordinary method of bracing inside the foundation, and he was much gratified at its success. Three sides of the excavation were kept practically in straight lines, and the fourth side bulged into the excavation for only 6 ins., so that there was no serious movement in the material back of the sheet piling. By this method the expensive and troublesome bracing inside the chimney was done away with, and the entire space inside of the excavation was available for the use of pile drivers. All piles were driven without moving the timbers, as would have been necessary with the ordinary method of bracing.

The author seems to imply that the plan of using piles under the foundation was adopted because the character of the soil was not known with sufficient definiteness.

Test borings were made, as stated, over the plot to a depth of — 75, but one preliminary boring was carried to rock, which was found at — 123. The original intention was to found the chimney upon rock, and if the depth had not been more than 75 ft. this plan would have been carried out, but it was not deemed feasible to carry the foundation down to — 123.

The borings showed, as stated, filled-in material to the depth of about 15 ft. Below this was a stratum of packed river mud or clay, about 10 ft. thick, and below this were strata of sand beginning with coarse sand on top, and gradually increasing in fineness until about the level of — 30, where fine beach-sand was encountered. This stratum of fine sand determined the length of piles.

Mr. Carr. A number of test piles were driven to refusal, and these piles indicated that sticks about 45 ft. long could be used. Very few piles, however, over 40 ft. long were driven. The piles were driven to a 1-in. penetration with a 2 500-lb. hammer dropping 20 ft.

In other respects, so far as the speaker is aware, the statements made by the author are correct, and the discrepancies noted are probably due to the fact than plans were sometimes changed in the field after the design had left the Chief Engineer's office.

Mr. Low. W. A. Low, Esq.—There was a little settlement of the chimney, but that was anticipated. Careful records were kept from week to week. The speaker took the levels once a week, and found that, as the chimney went up, it gradually settled a little, and to-day the total settlement is under 3 ins., most of that taking place before the chimney was completed. Since the chimney has been completed there has been added the weight of part of the three boiler room floors and the coal pockets, where the coal is stored. In the settlement, taken on all four corners at the base, a variation of not more than $\frac{1}{8}$ in. is found in any of the four corners compared with any of the others.

The speaker does not know how much of that settlement was due to shrinkage in the concrete.

The load on each pile under the chimney foundation was between 15 and 16 tons. The speaker does not know the load on the piles under the other part of the building.

The coal pockets are all waterproof, and there are no places where the coal can lodge, there being a complete system of hills and valleys. Mr. Pearson, the Consulting Engineer for the company, and Mr. Starrett, the Chief Engineer, have both had a good deal of experience in coal-pocket construction, and are, therefore, aware of the damage which can be done by the action of the coal on the iron.

As an instance, the coal pockets in the Kent Avenue power-house, in Brooklyn, may be mentioned. These pockets were lined with sheet iron, which corroded entirely through. The pocket at the Ninety-sixth Street power station was built of concrete, the spacing between the I-beams being filled with concrete and carried out 3 ins. beyond the face of the beams. Then the waterproofing—which was put in by a company whose formula, unfortunately, the speaker does not know—was applied, and it was found that it was of such a consistency that the dust of the coal knitted into it, and, so far, has not caused the least trouble.

The object of the belt conveyor is to take the ashes out when coal is not being hoisted. It runs usually during the night, but is sometimes run during the day, when the coal conveyor is not in operation. It was found to be too expensive to run the coal conveyor to take out the ashes alone, and, consequently, the belt conveyor was put in.

WERNER BOECKLIN, Jr., Assoc. M. Am. Soc. C. E.—The original plan was, as stated by the author, to handle the ashes by means of the returning coal conveyors, but a modification was found advisable—as the coal conveyors are not always running when it is necessary to remove the ashes, and as the running of an 800-ft. conveyor, merely to transport them a distance of 75 ft. would not be economical, a Robins Conveying Belt was installed for the purpose. Mr. Boecklin.

This conveyor consists, essentially, of two parts—belt and idlers. The belt is 16 ins. wide, reinforced along its middle by a coating of rubber $\frac{3}{16}$ in. thick to resist wear. The upper idlers supporting the belt and its load are made up of three 5-in. pulleys, two of which are set at an angle of 35° to the horizontal, thus troughing the belt and materially increasing its capacity. At the head end of this conveyor a circular brush in contact with the return belt, is operated from the head shaft and throws of any ashes which may adhere to the belt after passing the head pulley.

Ashes are brought by means of small cars from hoppers under the boilers and dumped on the floor at the east end of building, and from here they are shoveled by hand into a long horizontal hopper delivering into a bucket conveyor. This conveyor rises to the level of the bridge, and, running horizontally, delivers onto the belt.

J. D. KENT, Esq.—Two engines are used to drive the coal conveyors, and they are between 15 and 20 H.-P., but the speaker does not think they have yet been carded. The smaller engine, when running the belt conveyor, exerts about 6 H.-P. The wet ashes, as they come from the ash pan, do not cause any trouble, but the soot, taken from the back of the boilers, sticks or cakes on the belt and has to be cleaned off. The large buckets are affected in the same way. Mr. Kent.

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A PROPOSED METHOD FOR THE PRESERVATION OF TIMBER.

Discussion.*

By Messrs. Walter W. Curtis and R. Montfort.

Mr. Curtis. Walter W. Curtis, M. Am. Soc. C. E. (by letter).—The engineering profession should be ready at all times to give a hearing to the advocates of any new processes affecting the materials of construction; and to test such processes when it is possible to do so without too great expense; or when the possible resulting failure can be determined before the expenditure has become very large.

There is now, and will be in the future to a greater extent, a strong desire to experiment with new wood preservatives. The two methods now in use are old. The evidence of their value, in the writer's opinion, is sufficient to justify their general adoption, but is not as complete as could be desired, and, from the nature of things, is not likely to be. The difficulty of keeping tie records on long lengths of road for 15 and 20-year periods is such that those who desire to find fault with them will always have opportunity. One of the greatest dangers to the cause of timber treatment in this country is likely to be this desire for something new—and cheap.

In the writer's study of the question, it has been very amusing and instructive to read the circulars and endorsements therein, of 20 years ago, of methods long since gone by the board. It seems almost necessary to demand of the advocates of every new treatment, that it should first be tested for 10 or 15 years and then presented to the attention of the public. Certain it is that nothing short of such a test can be considered as conclusive, as to comparative value, in the case of ties. Mr. Curtis.

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* Continued from September, 1900, *Proceedings*. See May, 1900, *Proceedings*, for paper on this subject, by F. A. Kummer, Jun. Am. Soc. C. E.

Evidently, however, all engineers do not take quite such a pessimistic view of the matter. A committee of one of the Associations of Engineers of Maintenance-of-Way recently reported very strongly recommending the general adoption of a method of treatment of ties by painting them with or dipping them in a certain preservative compound; the advice being prefaced with and based upon a statement that by such treatment a life of 18 years could be secured from timber naturally having a life of but 6 years. The evidence to support such claims is very small and entirely insufficient to warrant any such general recommendations. In the advertising matter regarding one of the most recent processes offered the public, is the report of a learned professor, in which it is asserted that a life of from 13 to 15 years can be secured from soft wood ties treated by this particular method; and the evidence on which this is based is that poles so treated and placed in soil favorable to decay were sound after 2½ years.

The writer does not intend to decry either of these processes; they may be of great value, but the evidence thereof, as applied to ties, is extremely limited.

Mr. Kummer describes a treatment intended to overcome certain mechanical difficulties "in connection with creosoting, particularly railroad ties." Evidently, he refers to the fact that creosoting does not harden timber and that the usual allowance for ties, 10 lbs. of creosote per cubic foot, does not completely saturate the wood. This is undoubtedly true, but it seems hardly fair to condemn creosoted ties therefor, without some more definite data as to actual bad results. The recorded history of creosoted ties in the United States is not very great, but, so far as it goes, does not indicate that the deterioration from rail cutting is so serious as to detract greatly from the value of the treatment.

If Mr. Kummer has shown a means whereby such difficulties as do exist, however great or small they may be, can be removed, he has earned the thanks of the profession; but we must be careful lest, in running from the troubles of which we know, we do not also leave good qualities of which we are certain. As the paper did not state the comparative costs of the creo-resinate treatment and ordinary creosoting, the writer inquired of the company operating the process, and was told that the costs were the same, using equal amounts of preservative material in each case. For a tie creosoted with 9 to 10 lbs. per cubic foot the English records show a life of from 16 to 20 years; using a rail supported in a cast chair. If creosoted ties here are provided with tie-plates, at an additional cost of about 10 cents, there is every

Mr. Curtis. reason to expect as long service; indeed, Mr. Boggs, in his discussion* of the writer's paper, states that on the Houston and Texas Central R. R. 80% of the creosoted ties laid there in 1877 were still in service after 20 years, and that without a tie-plate.

The author's remarks as to the necessity for complete sterilization in creosoting are no doubt correct. In this respect the chloride of zinc treatment has an advantage, for, while sterilization there is probably advantageous, the use of heat is primarily to so season the wood and open the ducts, as to permit the entrance of the preservative fluid. This completely saturates the timber, if properly done, and the preserving and toxic agent is deposited throughout all parts of the timber. There is a decided lack of data as to the penetration of heat into ties during steaming, and the figures given in the paper are welcome and pleasing as well, demonstrating, as they do, the thoroughness of the steaming in Burnettizing. Mr. Kummer states, "with a temperature of 230° Fahr. in the cylinder, 178° was secured at the center (of the tie) in 2 hours, while with 290° at the outside, 249° was secured in 2 hours." Presumably, the 2 hours referred to is the time interval between the admission and exclusion of steam to and from the cylinder. In Burnettizing, it is customary to steam for at least 3 hours, the temperature being from 250° to 260° Fahr. The mean of the two cylinder temperatures given by Mr. Kummer is 260°, and the mean of the resulting tie temperatures is 213½°; so it is reasonable to conclude that the usual practice in Burnettizing results in complete sterilization. With reference to the use of a higher temperature under pressure, without injury to the timber, the writer has no data. He is not satisfied with any explanation of the philosophy of it, known to him, but the evidence seems to support the claim. The danger to be feared is not so much the checking of the wood, as the breaking down and disintegration of the fiber. It would be very interesting to know the relative absorption of preservative by timber treated according to the author's method and by the use of heat of 250° for the same length of time without pressure.

Table No. 1 shows the amount of absorption of preservative in green and in vulcanized timber. It is well known that it is impossible to inject any large amount of anything, even water, with the usual pressures and time of application, into timber which has not first been prepared for it by steaming. Before the value of vulcanizing can be admitted as a preparatory treatment, it must be shown that steaming at the usual heat would not secure the same results. Even if the time of such steaming with 250° temperature was one or two hours longer, in the writer's opinion, it would be much safer.

Table No. 2 shows the uniformity of absorption—or lack thereof. It will be noted that the range is from 5.62 to 16.87 lbs. per cubic foot;

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* *Transactions*, Am. Soc. C. E., Vol. xlii, p. 348.

Mr. Curtis.

the variation being just 200% of the lower extreme. Evidently, vulcanizing is not successful in entirely eliminating the idiosyncrasies of wood.

Mr. Kummer states that thorough sterilization is not generally secured during creosoting treatment. The writer understands that creosoting works generally use as high temperatures in steaming as do Burnettizing works, and continue it for as long or longer periods. What evidence has the author that the temperature of 212° at the center of the tie is not secured in creosoting?

The use of the creo-resinate process is recommended by the author for marine work. The writer recently received a letter from Mr. J. W. Byrnes, Superintendent of the timber treating works at Beaumont, Tex., whose experience in this line extends back some 30 years.

He states that Mr. J. W. Putnam made a test of a combination of resin and creosote, while operating the works at Pascagoula.

"He treated a quantity of sheet piling for the Galveston Wharf Company, about 10 years ago, and in less than 2 years the teredo had completely destroyed the wood. The President of the Wharf Company appointed me as the arbitrator in their behalf, and I recommended that Mr. Putnam be allowed to act in his own behalf. We had the piling cut out at the point of greatest exposure and divided them into short cuts and split them in small sections. The wood showed a perfect saturation, but, while only one third resin had been used to two-thirds oil, there was no odor or sign, other than color, that would indicate that a particle of dead oil had been used. The resin had totally destroyed the quality of the oil as a preservative against the teredo. About 1869, one of the leading chemists and physicians of New Orleans conceived the idea of treating wood with a mixture of resin-oil and resin, for marine use. We were at that time distilling resin-oil in connection with our coal-tar distilling works. We treated a number of samples of 4 x 4-in. pieces which he had fastened to piling or other structures at Lake Pontchartrain, Biloxi, Mississippi Sound, and Fort Phillip and Fort Jackson, at the mouth of the Mississippi River. The treatment seemed to give the wood a relish for the teredo. The Biloxi test was destroyed totally within 2 years. The Lake Pontchartrain and mouth of river samples held out for a year or two longer, but none to a greater extent of time than the natural wood. While the treatment of wood with a mixture of dead oil and resin may be effective as a preservative against decay, it has been positively proven by thorough tests that no good results will be obtained when used for marine work."

The process described by the author differs somewhat from that followed by Mr. Putnam; and it may be that the differences are sufficient to secure a more happy result. As a matter of history, however, the foregoing should be recorded.

Mr. Byrnes is strongly of the opinion that, to get satisfactory results from creosoted timber in marine work, it must be allowed to dry out for from 30 to 60 days after treating, when the creosote in the outer part of the timber becomes thick and gummy. If this is done, and the treatment has been properly given, he is satisfied that no difficulty

Mr. Curtis. will be experienced with the washing out of the creosote; and the durability of the work will prove satisfactory.

It is to be hoped that future experience with the creo-resinate treatment will demonstrate its value to be as great as the author anticipates. The writer, however, is less interested in improving upon creosoting practice than in approximating the results secured thereby at a less cost. The great need of the railroads to-day is to demonstrate or confirm the value of the zinc chloride treatment; and to improve thereon.

Mr. Montfort. R. MONTFORT, M. Am. Soc. C. E.—The writer's attention has been called to Mr. Boggs' communication, published in the September, 1900, *Proceedings*, in which the following statement is made:

> "R. Montfort, M. Am. Soc. C. E., Chief Engineer of the Louisville and Nashville Railway, is in a better position than any one known to the writer to speak with authority on the action of the teredo on creosoted piles, as his line traverses a number of salt water inlets along the Gulf Coast, and probably owns one of the oldest creosoting plants in the country. It is the writer's impression that he has entirely abandoned treating his piling, and is now protecting it with salt-glazed sewer pipe, as creosoting did not protect against the teredo."

Mr. Boggs is mistaken in his impression. The Louisville and Nashville Railroad Co., during the past twelve months constructed a large dock and warehouse at the foot of Commendencia Street, Pensacola, Florida, in which some 6 000 creosoted piles, averaging 70 ft. in length, and treated with 20 lbs. of creosote oil per cu. ft., were used. In addition to this, during the same period, about 2 000 000 ft. of sawed timber were used by this company on the wharf referred to, and for bridges, culverts, etc. It certainly, therefore, cannot be said that the Louisville and Nashville Railroad Company has entirely abandoned the use of creosote oil for protecting piling and timber against the teredo and against rot.

It is true that after a service of fourteen years the creosoted piles in trestles across Biloxi Bay, and Bay St. Louis, on the New Orleans and Mobile Division, and across Escambia Bay on the Pensacola and Atlantic Division of the Louisville and Nashville Railroad, were found to be attacked to a more or less serious degree by the teredo, and the piles in these trestles were further protected against the teredo by concrete or by vitrified clay pipe as described in a paper by the writer, read before this Society November 1st, 1893.* The same creosoted piling, driven in 1878, namely: 2 626 piles at Bay St. Louis, and 1 648 piles at Biloxi Bay, or a total of 4 274 piles, with the exception of 3 that have been replaced by new piles on account of rot, and 122 piles that were destroyed by the hurricane of October 2d, 1893, are still in use, giving good service and with prospect of lasting several years to come. Untreated piles at these bridges would not last, on an average, more than seven years as against rot, or six months against the teredo. Mr. Montfort.

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* *Transactions*, Vol. xxxi. p. 221.

Mr. Boggs does not state as to the treatment adopted, or the quality of the oil used in the piles of the Gulf, Colorado and Santa Fé Ry., at Galveston, Texas, which gave such poor results. From the writer's experience he is inclined to think there must have been some defect, either in the treatment or in the quality or quantity of the oil used that caused such results.

The writer believes Mr. George S. Valentine, who for years has been in charge of The Eppinger & Russell Co. Creosote Works, Long Island City, N. Y., treated piles in the early 70's that were driven in Galveston Bay, and are still doing service if they have not been destroyed by the recent hurricane.

In discussing the paper referred to, the writer said: *

> "In recent years, we have been experimenting with a mixture of resin and dead oil, with the hope that the resin will aid in fixing the oil and prevent it from being dissolved or washed out. Sufficient time has not elapsed to form any definite conclusion, although so far piles thus treated have given satisfactory results."

It is to be regretted that further experience with piles treated with dead oil of coal tar and resin has not given us the satisfactory results hoped for. In 1890, it having been found that the teredo had commenced to attack the piles in piers of East and West Pascagoula River bridges, driven in 1876, it was decided to strengthen the piers by replacing two piles at each end of each pier, consisting of sixteen piles. These piles were 80 ft. long, 10 ins. in diameter at the small end, and were driven 40 ft. into the bottom of the river. They were treated with a mixture of resin and oil in the proportion of 45 barrels of resin to 30 barrels of creosote oil, which is about the same proportion Mr. Kummer proposes to use. The total number of piles treated in this way and driven at these bridges was 88.

A recent examination of these piles for rot, by boring, showed that of the inside piles driven in 1876, and therefore 24 years old, only 8% showed rot in the heart, while of those treated with the mixture of oil and resin, driven in 1890, and only 10 years old, 43% showed rot in the heart. An examination by diver showed that the piles 24 years old, originally treated with creosote oil, were in better condition than the piles only 10 years old treated with the creosote oil and resin mixture.

From this it will be seen that the idea of mixing resin with the creosote oil did not originate with Mr. Kummer, but was used by the late J. W. Putnam, Assoc. M. Am. Soc. C. E., who did the work referred to, under contract, more than 10 years ago.

The writer hopes that Mr. Kummer's experience with piles so treated will be better than the results obtained on the Louisville and Nashville Railroad.

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* *Transactions*, Vol. xxxi, p. 246.

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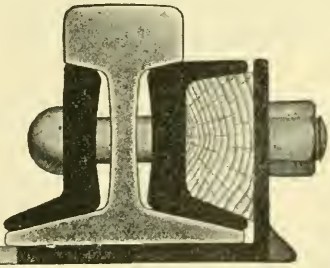

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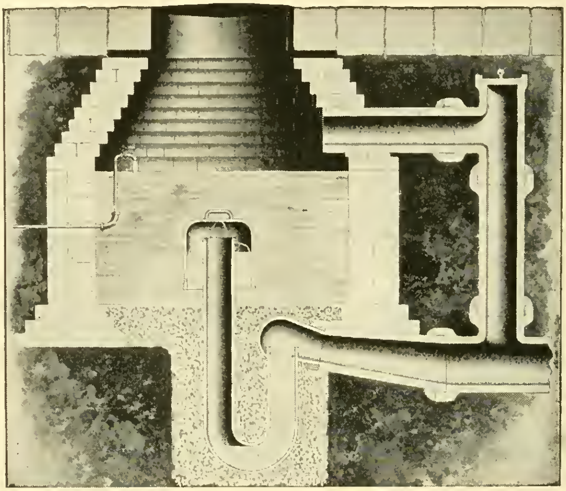

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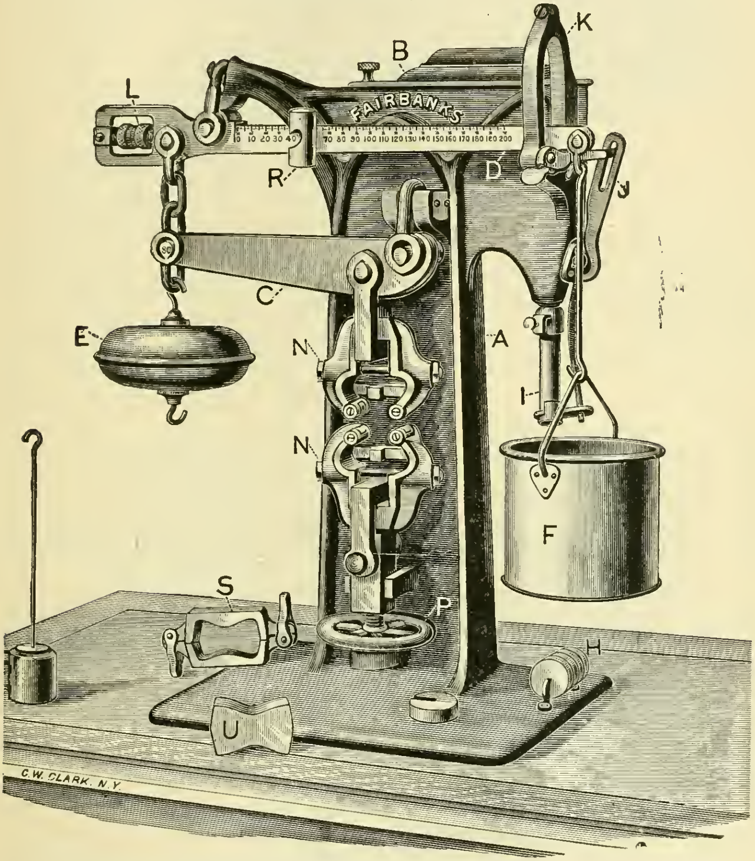

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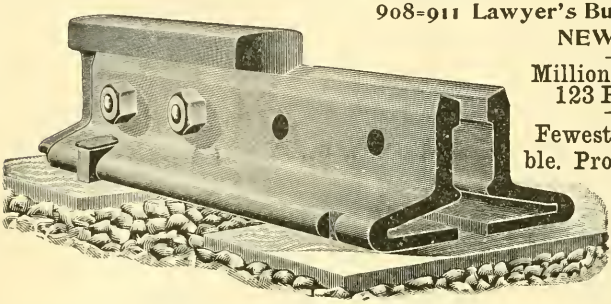

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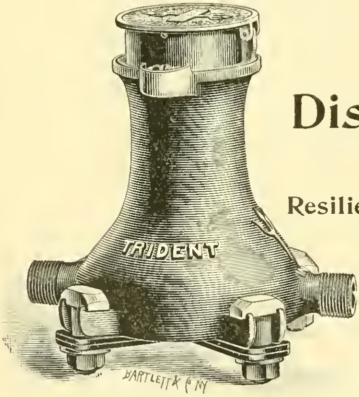

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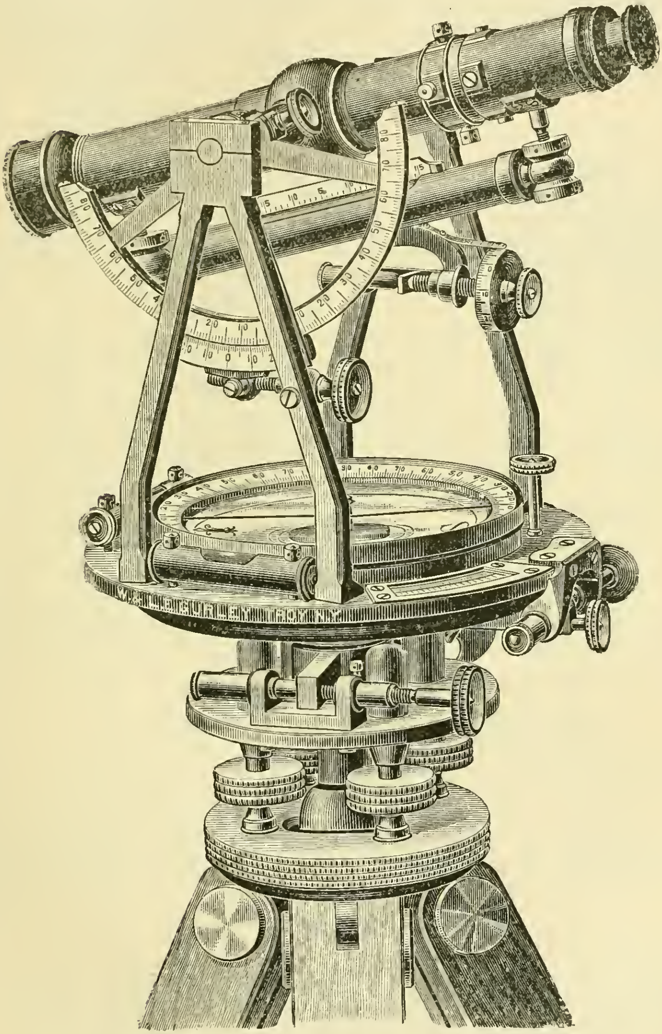
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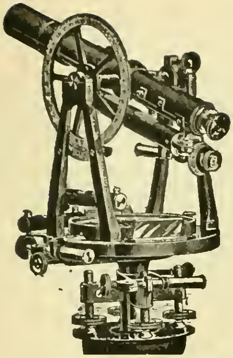

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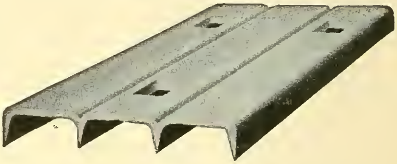

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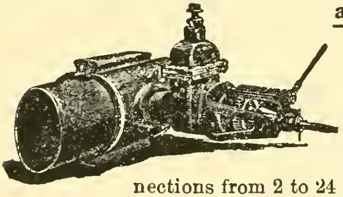

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Vol. XXVI. NOVEMBER, 1900. No. 9.

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OF THE

AMERICAN SOCIETY OF CIVIL ENGINEERS.

Edited by the Secretary, under the direction of the Committee on Publications.

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American Society of Civil Engineers.

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ON THE PROPER MANIPULATION OF TESTS OF CEMENT:—George F. Swain, Alfred Noble, George S. Webster, W. B. W. Howe, Louis C. Sabin, H. W. York.

◆

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PROCEEDINGS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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MINUTES OF MEETINGS.

OF THE SOCIETY.

November 7th, 1900.—The meeting was called to order at 8.40 P. M ; Vice-President Rudolph Hering in the chair; Charles Warren Hunt, Secretary; and present, also, 83 members and 9 visitors.

The minutes of the meetings of October 3d and 17th were approved as printed in *Proceedings* for October, 1900.

The following papers were presented for discussion: "Canals between the Lakes and New York," by Joseph Mayer, M. Am. Soc. C. E., and "The Economic Dimensions for a Waterway from the Great Lakes to the Atlantic," by George Y. Wisner, M. Am. Soc. C. E. The first of these papers was presented by the author, the second was presented in abstract by the Secretary, who also read written discussions by

Messrs. Thomas W. Symons, Isham Randolph, A. A. Schenck, and J. A. C. Wright.

Further discussion on these papers was postponed until the meeting of November 21st, 1900.

Ballots were canvassed, and the following candidates were declared elected:

As Members.

Frank Beckwith, Burlington, Iowa.
Loomis Farrington Goodale, St. Joseph, Mo.
Ira Grant Hedrick, Kansas City, Mo.
Calvin Wheeler Hendrick, New York City.
Sentaro Kondo, Tokyo, Japan.
James Wingate Rollins, Jr., West Roxbury, Mass.

As Associate Members.

Gavin Nelson Houston, Nyack, N. Y.
Arnold Charles Koenig, Grand Island, Neb.
James Alexander McCrea, Allegheny, Pa.
James Peter Whiskeman, Louisville, Ky.

The Secretary announced that at the meeting of the Board of Direction, November 2d, 1900, the ballot on the reconsideration of Gustave Robitscher Tuska was canvassed, and that Mr. Tuska was declared elected as a Member of the Society.

The Secretary announced the following deaths: William White Seitzinger, elected Junior October 2d, 1889; died September 21st, 1900. Arthur Towne Thomas, elected Member June 6th, 1894; died October 10th, 1900.

The Secretary announced that the Thirty-third Annual Convention of the Society will be held at Niagara Falls, N. Y., on Tuesday, Wednesday, Thursday and Friday, June 25th, 26th, 27th and 28th, 1901.

Adjourned.

November 21st, 1900.—The meeting was called to order at 8.40 p. m., Vice-President Rudolph Hering in the chair; Assistant Secretary McMinn acting as Secretary, and present, also, 85 members and 21 guests.

The discussion on the papers by Messrs. Joseph Mayer and George Y. Wisner, on Canals from the Lakes to New York, was continued. Messrs. Thomas C. Clarke and Edward P. North discussed the subject orally, and written discussions by Messrs. Thomas Monro, Frank A. Hinds, Elnathan Sweet and Lyman E. Cooley were presented.

The Assistant Secretary announced the death of Joseph Ruggles Richards, elected Associate February 4th, 1880; died September 28th, 1900.

Adjourned.

OF THE BOARD OF DIRECTION.

(Abstract.)

November 2d, 1900.—8.10 P. M.—Vice-President Hering in the Chair; Charles Warren Hunt, Secretary, and present, also, Messrs. Bensel, Clarke, Deyo, Knap, Morison, O'Rourke, Ricketts, Seaman, Turner and Whinery.

It was decided to undertake the preparation of a Subject Index to the first forty-four Volumes of *Transactions*, for issue as soon as possible to the membership.

The place for holding the Thirty-third Annual Convention was fixed as Niagara Falls, N. Y., and the time, Tuesday, Wednesday, Thursday and Friday, June 25th, 26th, 27th and 28th, 1901.

Announcement was made of the appointment of Messrs. Joseph Mayer, Arthur N. Talbot and S. E. Tinkham as a Committee to Recommend the Award of Prizes for the year ending with the month of July, 1900.

The reconsideration ballot in the case of Gustave Robitscher Tuska, for admission as Member, was canvassed, and Mr. Tuska was declared elected.

The following resignations were presented and accepted:

Julian Edward Caccia, Assoc. M. Am. Soc. C. E.; Thomas Tainter Watson, Jun. Am. Soc. C. E.

A Committee was appointed to report on the subject of an invitation to this Society to co-operate in a proposed International Engineering Congress to be held in Glasgow during 1901.

Applications were considered and other routine business transacted.

Adjourned.

ANNOUNCEMENTS.

In accordance with the resolution of the Board of Direction the House of the Society is open every day, except Sunday, from 9 A. M. to 10 P. M.

MEETINGS.

Wednesday, December 5th, 1900.—8.30 P. M.—A regular business meeting will be held. Ballots for membership will be canvassed, and a paper by Ewald Schmitt, Assoc. M. Am. Soc. C. E., entitled, "A Direct Method of Spacing Rivets and Finding the Position, Etc., of Stiffeners in Plate Girders," will be presented for discussion.

This paper is printed in the current number of *Proceedings*.

Wednesday, December 19th, 1900.—8.30 P. M.—A regular meeting will be held at which a paper entitled "Some Peculiar Railroad Bridge Accidents," by J. I. Boggs, Assoc. M. Am. Soc. C. E., will be presented.

This paper is printed in the current number of *Proceedings*.

Wednesday, January 2d, 1901.—8.30 P. M.—A regular business meeting will be held. Ballots for membership will be canvassed, and a paper entitled "The Kinzua Viaduct of the Erie Railroad Company," by C. R. Grimm, M. Am. Soc. C. E., will be presented for discussion.

This paper is printed in the current number of *Proceedings*.

CORRECTION OF MINUTES

Of Meeting of October 3d, 1900.

In the minutes of the meeting of October 3d, 1900, substitute for the list of candidates there given as elected by the Board of Direction,* October 2d, 1900, the following:

As Associates.

Thane Ross Brown, Milwaukee, Wis.
Alfred William Thorn, Buffalo, N. Y.

As Juniors.

William Godfrey Arn, Nashville, Tenn.
Sam Wigfall Bradshaw, Steelton, Pa.
John Bobbs Cameron, Princeton, Ind.
Benjamin Harrison Flynn, Columbus, Ohio.
Henry England Grimm, St. Louis, Mo.
Brantz Mayer, Ozone, Tenn.
Clifford Milton Stegner, New York City.
John Sharp Stiger, Jr., Mendham, N. J.
Warren Ayres Tyrrell, St. Louis, Mo.

---

* The gentlemen named in the list printed by mistake were elected to the respective grades on May 1st, 1900.

ANNUAL MEETING.

The forty-eighth Annual Meeting will be held at the Society House, January 16th and 17th, 1901. The Business Meeting will be called to order at 10 o'clock on Wednesday morning. The annual reports will be read, officers for the ensuing year elected, members of the Nominating Committee appointed, amendment to the Constitution considered, and other business transacted.

The arrangements for excursions and entertainments will be announced later.

PROPOSED AMENDMENT TO THE CONSTITUTION.

The following proposed amendment to the Constitution has been received by the Secretary, and has been sent to the Corporate Members of the Society, in accordance with the provisions of Section 2 of Article IX of said Constitution:

"Amend Section 5 of Article II by adding the following:

"*The Board of Direction may transfer any Junior elected prior to March 4th, 1891, to the grade of Associate.*"

This amendment is proposed by George S. Morison, S. Whinery, Joseph M. Knap, John Bogart and C. C. Schneider.

NOMINATING COMMITTEE.

Heretofore, seven members of the Nominating Committee, one from each of the Geographical Districts, have been elected annually at the Annual Convention.

The amendment to the Constitution adopted October 3d, 1900, provides that this election shall take place at the Annual Meeting.

The usual blank request for suggestions as to representatives of each district, for presentation to the meeting, will soon be mailed to Corporate Members.

ANNUAL CONVENTION OF 1901.

The Thirty-third Annual Convention of the Society will be held at Niagara Falls, N. Y., on Tuesday, Wednesday, Thursday and Friday, June 25th, 26th, 27th and 28th, 1901.

MONTHLY LIST OF RECENT ENGINEERING ARTICLES OF INTEREST.

(October 11th to November 13th, 1900.)

NOTE.—*This list is published for the purpose of placing before the members of the Society the titles of current engineering articles, which can be referred to in any available engineering library, or can be procured by addressing the publication directly, the address and price being given wherever possible.*

LIST OF PUBLICATIONS.

In the subjoined list of articles references are given by the number prefixed to each journal in this list.

(1) *Journal*, Assoc. Eng. Soc., 257 South Fourth St., Philadelphia, Pa., 30c.
(2) *Proceedings*, Eng. Club of Phila., 1122 Girard St., Philadelphia, Pa.
(3) *Journal*, Franklin Inst., Philadelphia, Pa., 50c.
(4) *Journal*, Western Soc. of Eng., Monadnock Block, Chicago, Ill.
(5) *Transactions*, Can. Soc. C. E., Montreal, Que., Can.
(6) *School of Mines Quarterly*, Columbia Univ., New York City, 50c.
(7) *Technology Quarterly*, Mass. Inst. Tech., Boston, Mass., 75c.
(8) *Stevens Institute Indicator*, Stevens Institute, Hoboken, N. J., 50c.
(9) *Engineering Magazine*, New York City, 30c.
(10) *Cassier's Magazine*, New York City, 25c.
(11) *Engineering* (London), W. H. Wiley, New York City, 35c.
(12) *The Engineer* (London), International News Co., New York City, 35c.
(13) *Engineering News*, New York City, 15c
(14) *The Engineering Record*, New York City, 12c.
(15) *Railroad Gazette*, New York City, 10c.
(16) *Engineering and Mining Journal*, New York City, 15c.
(17) *Street Railway Journal*, New York City, 35c.
(18) *Railway and Engineering Review*, Chicago, Ill.
(19 *Scientific American Supplement*, New York City, 10c.
(20) *Iron Age*, New York City, 10c.
(21) *Railway Engineer*, London, England.
(22) *Iron and Coal Trades Review*, London, England.
(23) *Bulletin*, American Iron and Steel Assoc., Philadelphia, Pa.
(24) *American Gaslight Journal*, New York City, 10c.
(25) *American Engineer*, New York City, 20c.
(26) *Electrical Review*, London, England.
(27) *Electrical World and Engineer*, New York City, 10c.
(28) *Journal*, New England Water-Works Assoc., Boston, 75c.
(29) *Journal*, Society of Arts, London, England.
(30) *Annales des Travaux Publics de Belgique*, Brussels, Belgium.
(31) *Annales de l' Assoc. des Ing. Sortis des Ecôle Spéciales de Gand*, Brussels, Belgium.
(32) *Memoirs et Compt Rendu des Travaux*, Soc. Ing. Civ. de France Paris, France.
(33) *Le Génie Civil*, Paris, France.
(34) *Portefeuille Economique des Machines*, Paris, France.
(35) *Nouvelles Annales de la Construction*, Paris, France.
(36) *La Revue Technique*, Paris, France.
(37) *Revue de Mecanique*, Paris, France.
(38) *Revue Générale des Chemins de Fer et des Tramways*, Paris, France.
(39) *Railway Master Mechanic*, Chicago, Ill.
(40) *Railway Age*, Chicago, Ill., 10c.
(41) *Modern Machinery*, Chicago, Ill., 10c.
(42) *Transactions*, Am. Inst. Elec. Eng., New York City, 50c.
(43) *Annales des Ponts et Chaussees*, Paris, France.
(44) *Journal*, Military Service Institution, Governor's Island, New York Harbor, 75c.
(45) *Mines and Minerals*, Scranton, Pa., 20c.
(46) *Scientific American*, New York City, 10c.
(47) *Mechanical Engineer*, Manchester, England.
(48) *Zeitschrift des Vereines Deutscher Ingenieure*, Berlin, Germany.
(49) *Zeitschrift für Bauwesen*, Berlin, Germany.
(50) *Stahl und Eisen*, Duesseldorf, Germany.
(51) *Deutsche Bauzeitung*, Berlin, Germany.
(52) *Rigasche Industrie-Zeitung*, Riga, Russia.
(53) *Zeitschrift des oesterreichischen Ingenieur und Architekten Vereines*, Vienna, Austria.
(54) *Den Tekniske Forenings Tidsskrift*, Copenhagen, Denmark.
(55) *Ingeniören*, Copenhagen, Denmark.
(56) *Teknisk Tidskrift*, Stockholm, Sweden.
(57) *Teknisk Ugeblad*, Christiania, Norway.
(58) *Proceedings*, Eng. Soc. W. Pa., 410 Penn Ave., Pittsburg, Pa. 50c.
(59) *Transactions*, Mining Institute of Scotland. London and Newcastle-upon-Tyne.
(61) *Proceedings*, Western Railway Club, 225 Dearborn St., Chicago, Ill., 25c.
(62) *American Manufacturer and Iron World*, 59 Ninth St., Pittsburg, Pa.
(63) *Minutes of Proceedings*, Inst. C. E., London, England.

NOTE.—There are no references made in this month's list to German and Swedish periodicals.

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Essais Préliminaires à la Navigation Aérienne au Long Cours.* Léo Dex. (36) Serial beginning May 10, ending Sept. 10.
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The Manufacture of Steel on the Basic Open-Hearth. Thomas Turner. (47) Sept. 8.
Applications of Petroleum to Metallurgy and the Glass Industry.* (19) Oct. 20.
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A New Method of Producing High Temperatures. Ernest F. Lange, F. C. S. (13) Nov. 1.
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Military.

War Material at the Paris Exhibition.* (12) Serial beginning Aug. 31, ending Oct. 5.
Armor Plate Trials.* (12) Oct. 5.
Maximite: A New High Explosive for Armor-Piercing Projectiles.* (13) Nov. 1.
Canons à Tir Rapide de Bord, Champagne, Siège et Place. M. G. Canet. (32) Sept.
Progrès Réalisés dans la Fabrication des Blindages depuis 1889. M. E. Delmas. (32) Sept.

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Mining.

An Indian Colliery and Its Miners. Henry M. Cadell. (59) Pt. 4.
An Ordinary Miner's Boring-Machine Adapted for Boring against Wastes.* Robert Martin. (59) Pt. 4.
Mining Practice in Butte, Montana, Copper Mines.* R. B. Brinsmade. (45) Serial beginning Oct., ending Nov.
Tong Colliery, Kaiping, North China.* Thomas Webster (22) Oct. 5.
Compressed-Air Haulage in Coal Mining. J. H. Bowden. (15) Oct. 12.
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The Effect of Contractions in Area of Passages in Mine Ventilation.* Paul Petit. (16) Oct. 13.
How Mines Should Be Examined?* O. H. Packer. (16) Oct. 20.
Tapered *vs.* Non-Tapered Props.* S. J. Bridges. (22) Oct. 26.
Coal Mines at Streator.* A. Dinsmore. (45) Nov.
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Some Notes on Rail Joint Fastenings.* F. C. Schmitz. (15) Serial beginning July 27, ending Oct. 26.
Low-Pressure Pneumatic System of Working Points and Signals.* (21) Serial beginning August, ending Oct.
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Highway Grade Crossing Alarms. J. S. Evans. (18) Oct. 13.
The Street Railway Situation in the Two Kansas Cities.* (17) Oct. 13.
Electric Railway Practice in France.* A. N. Connett. (17) Oct. 13.
The Street Railways of Rio de Janeiro.* (17) Oct. 13.
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*Illustrated.

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The Ozonization of Water. George A. Soper. (28) Sept.
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Wooden Joints in Cast-Iron Water Mains. William Murdoch. (28) Sept.

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*Illustrated.

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Performance of the Twelve-Million-Gallon Allis Pumping Engine at Hackensack, N. J., and Comparative Data from Tests of the Best Three Contemporary Pumping Engines. Prof. James E. Denton. (8) Oct.
The Condition of Water and Power Development in Southern California.* L. K. Sherman, M. W. S. E. (4) Oct.
Economical Dimensions of Rectangular Filter Beds.* John H. Gregory, Jun. Am. Soc. C. E. (13) Oct. 11.
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Pumping Engines for the Coolgardie Pipe Line.* (13) Oct. 18.
Lifting Water by Compressed Air.* Clark Howell. (20) Oct. 25.
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Standard Methods of Water Analysis. (13) Nov. 1.
Diagram Giving Discharge of Pipes by Kutter's Formula.* John H. Gregory, Jun. Am. Soc. C. E. (14) Nov. 3.
The Pollution of Public Water Supplies. (14) Nov. 3.
The St. Lawrence Power Plant at Massena.* (14) Nov. 3.
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Another Great Hydraulic Power Plant: The St. Lawrence Power Company's Undertaking.* (20) Nov. 8.

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Hoogli River—Proposed Deep Water Approach to Calcutta.* Lindon W. Bates. (4) Oct.
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Les Ports Tunisiens.* G. Leugny. (36) Oct. 25.
L'Élévation Mécanique de Bief en Bief des Eaux d'Alimentation du Canal de Bourgogne. M. Ed. Watteeuw et M. D. Bouckaert. (31) Pt. 3, 1900.
Redressement de l'Escaut en Aval d'Anvers. C. J. van Mierlo. (31) Pt. 3, 1900.

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*Illustrated.

NEW BOOKS OF THE MONTH.

Unless otherwise specified, books in this list have been donated to the Library by the Publisher.

TEXT-BOOK ON THE MECHANICS OF MATERIALS,

And of Beams, Columns and Shafts. By Mansfield Merriman. Ninth Edition, Revised. Cloth, 9 x 6 ins., 368 pp. New York, John Wiley & Sons, 1900. $4.00. (Donated by the Author.)

The preface states that this work is designed for the use of classes in technical schools and colleges. Extended tables of the results of tests on different kinds and qualities of materials are not given. The attempt, however, has been made to state average values of the quantities which express the strength and elasticity of what may be called the six principal materials. The headings of chapters are: Resistance and Elasticity of Materials; Pipes, Cylinders and Riveted Joints; Cantilever Beams and Simple Beams; Restrained Beams and Continuous Beams; Columns or Struts; Torsion and Shafts; Combined Stresses; The Strength of Materials; The Resilience of Materials; Tension and Compression; Flexure of Beams; Shear and Torsion; Apparent Stresses and True Stresses; Stresses in Guns; Plates, Spheres and Columns; Appendix.

TREATISE ON HYDRAULICS.

By Mansfield Merriman. Seventh Edition, Revised. Cloth, 9 x 6 ins., 427 pp., illus. New York, John Wiley & Sons, 1900. $4.00. (Donated by the Author.)

In this edition, the author calls attention to the recent experiments of Marx, Wing, and Hoskins on flow in steel and wooden pipes, and to those of Bazin on flow over dams. The Contents are: Introduction; Hydrostatics; Theoretical Hydraulics; Flow Through Orifices; Flow Over Weirs; Flow Through Tubes; Flow in Pipes; Flow in Conduits and Canals; Flow in Rivers; Measurement of Water-Power; Dynamic Pressure of Flowing Water; Naval Hydromechanics; Water-Wheels; Turbines.

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Atlantic City Board of Water Commrs. 1 pam.
Chamber of Mines of Victoria. 1 pam.
Colo. Agricultural Exper. Station. 1 pam.
VIIIe Congrès International de Navigation, Paris, 1900. 6 bound vol., 3 pam.
Eiffel, G. 2 bound vol.
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JUNIOR.	
Watson, Thomas Tainter	Nov. 2, 1900

DEATHS.

Emerson, George Dana.............Elected Member Sept. 18th, 1872; died Sept. 28th, 1900.
Richards, Joseph Ruggles...........Elected Associate Feb. 4th, 1880; died Sept. 28th, 1900.
Seitzinger, William White..... ...Elected Junior Oct. 2d, 1889; died Sept. 21st, 1900.
Thomas, Arthur Towne.............Elected Member June 6th, 1894; died Oct. 10th, 1900.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS AND DISCUSSIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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A DIRECT METHOD OF SPACING RIVETS AND FINDING THE POSITION, ETC., OF STIFFENERS IN PLATE GIRDERS.

By E. Schmitt, Assoc. M. Am. Soc. C. E.

To be Presented December 5th, 1900.

Although the scope and importance of this paper are not of a nature requiring phrases or mottoes to introduce it, the writer cannot refrain from stating in a few words the reasons actuating him in writing it and in constructing the accompanying diagrams and tables.

Even if one knows by heart some of the more important formulas of applied structural mechanics, the following axiom will govern their general usefulness :

"Good formulas, however short, are of almost no value in hurried daily practice, where quick and accurate results are expected, unless presented in the shape of tables."

These, again, are serviceable only when in such profusion, and so extended into final results, that, after having been consulted once, no further computations need be performed. They must, also, meet current demands regarding the information they are expected to furnish for all the ordinary problems coming under their headings.

Note.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers with discussion in full will be published in *Transactions*.

The writer, and no doubt many others with him, when making structural computations, not having at his disposal labor-saving devices, in the shape of suitable diagrams and tables, and when not wishing to depend on results of rules of thumb, has found the foregoing axiom to be vexatiously true.

Having had to compute plate girders quite frequently, and having found the figuring of rivet spacing, buckling values of webs, location of stiffeners, etc., by formulas, a slow, time-consuming operation, the writer determined to make a short cut for solving such problems, and hopes that the burdens of those who have to compute plate girders will be lessened by the use of the method presented herewith.

It is hoped that the reader will not object to being reminded of the virtues possessed by the "method of graphical statics," which excels greatly the analytic method of solving problems in structural mechanics. It furnishes at once not only particular, but all possible, values and conditions of forces and stresses acting upon structures. Formulas of the analytic method, on the contrary, furnish only one value at a time. Graphical statics reveals to the eye the play of forces and stresses; nothing is hidden; it gives object lessons instead of abstract demonstrations. It possesses, in itself, a complete check of its operations and its results, or it can be made to do so in an easy manner. The analytic method, it is true, gives absolutely correct results, but only in theory, and for the assumed conditions. Such exact fulfilment in assumptions and results cannot be realized in any case, in the working of the forces in the universe or in any structure.

All who have used both methods agree that the graphical is shorter, more comprehensive, and in full accord with assumptions and practical conditions. The results obtained thereby are just as accurate and as true as the assumed conditions on which the computation is based.

Versatility with this method (acquired by constantly using it) is necessary to appreciate fully its perfect qualities in solving the most simple as well as the most intricate problems, statical or elastic, of applied mechanics. It is to be mentioned, however, that all graphical solutions start from analytic formulas, and can never be applied to advantage without first having had a thorough training in the analytic handling of the problems of applied mechanics. When a problem has to be solved, both methods should be used, each at the proper time, the analytic formulas to be consulted in advice.

No explanation need be given for the manner in which the shear diagram for the vertical shearing stress has been made use of, as will be seen in what follows, for determining the rivet spacing by means of the vertical shear ordinates, directly, although the rivets are acted upon by a horizontal force. The intensity of both these stresses is the same at any point in the web, and since, for the purpose mentioned, the magnitude only of the horizontal shearing stress is of importance, no notice need be taken of its real sense and direction. The position in which the magnitude of this force is found in the shear diagram, is besides a very convenient one for the solution of the problem.

The method to be set forth to determine the rivet pitch and also that point from which on, toward the end of the girders, stiffeners will be required, is graphical, and requires the plotting of the shear curve for the particular loading of the girder, which in any case is a simple performance. For convenience and clearness in carrying out operations, it will be found best to arrange the shear curve immediately above or below the girder to be designed. The depth of the girder may be drawn to any reasonable scale which will allow accurate measurement of the rivet spacing.

Assuming the reader to be familiar with the theory and the designing of plate girders in general, and that he has, for a particular case, decided upon the thickness of the web and the size of the rivet; further, that he has determined the rivet value by means of a rivet table, to be found in any of the mill handbooks (see also the diagram and tables at the end of this paper), we can proceed to refer to the well-known rivet formula:

Let S = shear at any point X in the length of the girder;
h = depth of the girder between the upper and lower pitch lines;
p = the pitch, or spacing, of the rivets to be found;
v = the rivet value;
$p = \frac{v\,h}{S}$; transforming, we have then:
$\frac{h}{p} = \frac{S}{v}$; that is, the depth of the girder is to the rivet pitch, as is the total shear to the rivet value.

Referring now to Fig. 1, let $A\ B = h\ h$ be the span of the girder, and $C\ D$ the shear curve, drawn in reference to the base line $E\ F$. Set off vertically downward at points A and B the depth h of the girder, as $A h$, $B h$.

Choose any section, as X, and draw a vertical line $c\ e\ a\ b$. The ordinate $c\ e$ will then represent the total shear at X for the panel to the right of e. From the point e in the shear diagram set off, toward the right hand, the rivet value $e\ v$, in the scale of shears. Produce the line $c\ v$. Through the point a, in the girder diagram, draw a parallel line intersecting $h\ h$ in p, then the distance $b\ p$ is equal to the required rivet spacing for the shear at the point X. In the similar triangles $c\ e\ v$ and $a\ b\ p$ we have the proportion:

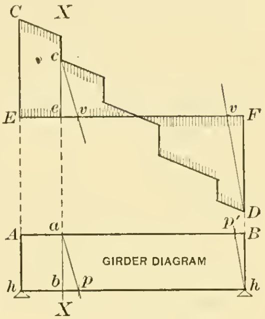


Fig. 1.

$$a\,b : p\,b :: c\,e : e\,v,$$

or,

$$h : p :: S : v,$$

and as before,

$$\frac{h}{p} = \frac{S}{v}.$$

To express $b\,p$ in inches, measure the length of the line $b\,p$ in the scale in which the depth h of the girder $A\ B$ has been set off.

We will now proceed to find the position of the stiffeners, or that point s, from which on, toward the abutments, stiffeners will be required.

Referring to Fig. 2, we make use of the shear diagram as before. Set off vertically, in the shear scale, above and below the base line $E\ F$, the buckling, or total shear value w of the web, whatever value the designer has determined to use.

The shear stress between the lines $E F$ and $G\ H$ (in the upper part of the diagram) is taken care of by the web. The shear stress beyond the line $G\ H$ will have to be taken care of by stiffeners. Stiffeners will be required therefore, toward the ends beyond the point s, where the line $G\ H$ intersects the shear curve $C\ D$. (See also the lower half of the shear diagram.)

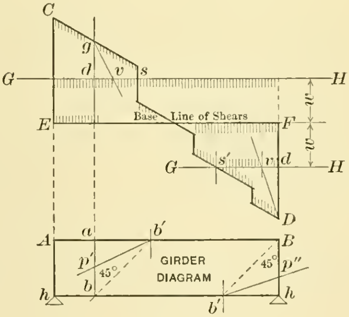


Fig. 2.

From the theory of the plate girder, it is known that stiffeners, if required at all, must be spaced at distances equal to the depth of the girder. It is also known that at any point in the web, as mentioned before, horizontal and vertical shearing stresses are of the same intensity, and that therefore the spacing of the rivets in the stiffeners can be found in the same manner as for the flange angles; considering, however, that only that part of the shearing stress above the line $G\,H$ (in reference to the base line $E\,F$ and the upper part, Fig. 2), and from the point s on, toward the abutments, has to be taken care of by the stiffeners. The same applies to the lower half of the diagram.

Proceeding now to space off from the point s, distances d, ... etc., equal to the depth of the girder, the ordinate $d\,g$, above the points d, d, represents the surplus shears coming upon the respective stiffeners.

From the stiffener panel-points d set off again the rivet value r, as $d\,r$, produce the line $g\,v$ for any of the stiffeners, and through the point b' in the girder diagram, corresponding to the particular stiffener, draw a normal line to the direction of the line $g\,v$ intersecting the stiffener line $a\,b$ in the point p'. The point b' having been located at a distance $a\,b'$ equal to the depth of the girder, from the point a, by means of the 45° line $b\,b'$.

In the similar triangles $b'\,a\,p'$ and $g\,d\,r$, the same ratio $\frac{h}{p'}, = \frac{S}{v}$ previously found for the flange angles, will obtain, as it should from the statements previously made.

The spacing of the rivets in the stiffeners, thus found, will be, usually, greater than the maximum spacing permissible in rivet work, and should be limited to this accordingly. The size of the stiffener sections may be determined by treating them as columns (with flat ends). Since, however, they are riveted at short intervals along their length, they may be computed for simple compression in ordinary cases, but they should always be applied in the form of angle irons.

The method shown for rivet spacing for particular panels, and for particular shearing stresses, can be reversed in such a manner as to determine the length of the panels in which a certain assumed rivet spacing, for example, 6-in., 4-in. or 3-in., shall take place.

In the girder diagram $A\,h\,B\,h$, Fig. 3, set off, from the point h, the desired rivet spacing, as $h\,p^3$, $h\,p^4$, $h\,p^6$.... From these lines draw lines to the point A, as a pole. Now, in the shear diagram, $C\,E\,F\,D$, set off from E the rivet value v, as $E\,v$. Through the point v draw parallel lines to the lines $A\,p^3$, $A\,p^4$, $A\,p^6$,.... as $v\,p^3$, $v\,p^4$, $v\,p^6$.... intersecting the end shear lines $C\,E$ and $E\,F$ in p^3, p^6.... etc. Through these points, p^3, p^4, p^6, in the shear diagram draw parallel lines to the base line $E\,F$. From the intersection points of these horizontal lines with the shear curve drop verticals to the base line $E\,F$. These ordinates will divide the girder into the desired panels, in each of which the respective assumed rivet spacing will obtain as in Fig. 3.

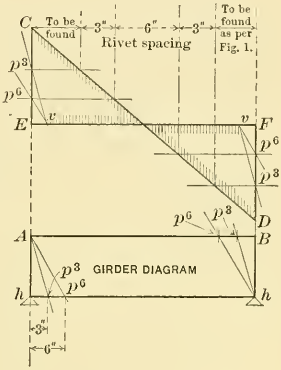


FIG. 3.

In like manner (see Fig. 4) we can find, say for the end of a girder, the rivet value v for a certain pitch by simply setting off the pitch $h\,p$ = say 3 ins. in the girder diagram, and proceeding in the reverse order of the operations carried out in Fig. 1, by drawing the line $A\,p$ and a line $C\,v$ parallel to it through the point C intersecting the base line of the shears in v, then $E\,v$ is the necessary rivet value. Scaling this value and inspecting the rivet table, the thickness of the web and the size of the rivet can be chosen with due regard to practical considerations.

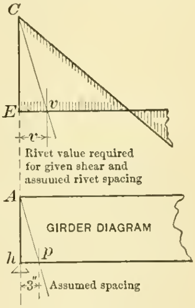

C
E
v
v
Rivet value required for given shear and assumed rivet spacing
A
GIRDER DIAGRAM
h
p
3"
Assumed spacing

FIG. 4.

The method set forth, so far, gives all the data required for rivet spacing in ordinary practice and theory.

In railroad work, the computation must include, besides the horizontal component due to the main shear, the local vertical effect due to a maximum wheel load. This wheel load is usually assumed to be uniformly distributed over one or two sleeper spaces of 2 to $3\frac{1}{2}$ ft.

As the foregoing forces act at right angles to one another, their resultant must be first ascertained before the proper rivet spacing can be determined.

Let $S =$ main shear, acting horizontally;
$h =$ depth of girder, in feet;
$Q =$ maximum wheel load, acting vertically;
$k =$ the sleeper space, in feet.

Then $\frac{S}{h} =$ shear per lineal foot, due to the main shear,

$\frac{Q}{k} =$ " " " " " " local shear.

The resultant of these two forces, to be taken up by n rivets per foot, will be:

$$r = \sqrt{\left(\frac{S}{h}\right)^2 + \left(\frac{Q}{k}\right)^2}$$

Expressing the sleeper space k in terms of the depth of girder h, by putting $k = \frac{1}{q} h$, or $q = \frac{h}{k}$, the above formula can be written

$$r = \frac{\sqrt{S^2 + \left(Q \frac{h}{k}\right)^2}}{h}$$

Further, let $n =$ number of rivets per lineal foot;
$v =$ the rivet value;
$p =$ the rivet pitch;

also $n p = 1$ (ft.), $p = \frac{1}{n}$ and $n = \frac{1}{p}$, and considering that the condition $n v = r = \frac{v}{p}$ must also be fulfilled, we have

$$\frac{v}{p} = \frac{\sqrt{S^2 + \left(Q \frac{h}{k}\right)^2}}{h}$$

This formula is, as will be found by comparison, identical with the original rivet formula, presented at the beginning of this paper, and we will use it again as the basis in the determination of the rivet spacing in the present case by evaluating graphically the term under the root, which is the aggregate resultant of all the shearing forces acting upon the n rivets at section X.

This is readily done by forming the "triangle of forces," with the components S and $Q \frac{h}{k}$, acting at right angles to one another. The hypothenuse of this triangle will at once represent the term

$$\sqrt{S^2 + \left(Q \frac{h}{k}\right)^2}$$

Referring now to Fig. 5 and section X, let $C F$ represent the shear curve for the rolling load, $G D$ that for the uniform load, both in reference to the line $E F$. Then the ordinate $c u$ will be in magnitude equal to S, and will form one of the sides of the triangle of forces we desire to construct. Set off in the shear diagram horizontally from the point E the maximum wheel load Q, as $E q$ (in the scale of shears). Similarly, set off in the girder diagram the tie, or sleeper space k (in the scale used for laying off depth of girder), as h K. Draw the imaginary line $K A$ and parallel to it another, $q d$, through the point q in the shear diagram, piercing the end shear line in d; then $E d$ is equal to the magnitude of the local vertical shear component $Q \frac{h}{k}$, which must be joined at right angles to S.

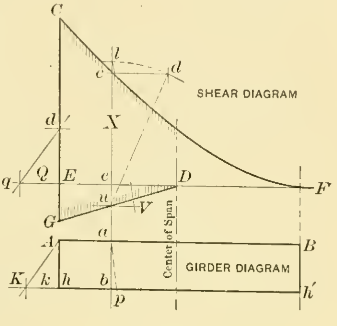


Fig. 5.

In the similar triangles $A h K$ and $d E q$, we have—

$$h K : A h :: E q : d E,$$

or,

$$d E = \frac{E q \times A h}{h K} = Q \frac{h}{K}$$

Now set off, horizontally, from point c in the shear curve $C E$, this value $E d$, as $c d$; draw the imaginary line $u d$ (produced in the diagram), then $u d$ is equal to the magnitude of the resultant referred to before. Bring this resultant into a vertical position with a compass, using the point u as a center for describing the arc $d l$. Set off, further, from the point u, horizontally, the value of the adopted rivet, as $u V$; draw the imaginary line $V l$, and parallel to it another, through the point a in the girder diagram, piercing the base line of the girder in the point p; then $b p$ is equal to the required rivet spacing at the section X, depending on the combined action of the several shearing stresses mentioned.

Practical Points: Web Thickness, Panel Lengths, Etc.—As stated, the web thickness is usually proportioned for the greatest shear and for buckling. For this case no stiffeners are required to assist the web. If, however, the web is calculated for simple shear only, or for an intermediate condition between buckling and shear, which is also frequently done, then the method just shown for locating the stiffeners is to be used.

The rivet value of a rivet depends on the shearing capacity of the particular rivet and the web thickness in which it bears, etc., and the lesser of the two values, usually that for bearing, must be adopted to determine the pitch. If this pitch should be found to be less than the minimum spacing permissible, a larger rivet or a heavier web must be resorted to. To obtain, under certain circumstances, a sufficient rivet value as regards bearing, without changing either the diameter of the rivet, which may be a maximum, or the spacing, which may be a minimum, already, a deeper web must be selected.

This depth can be determined at once by means of the diagram, Fig. 4. In the case just stated the known quantities are: The total shear, the rivet value, consequently the direction of the line $C\ v$, to which draw a parallel line $p\ A$ through the point p, intersecting the abutment line of the girder in the point A; then $A\ h$ is equal to the depth of the girder which is sought.

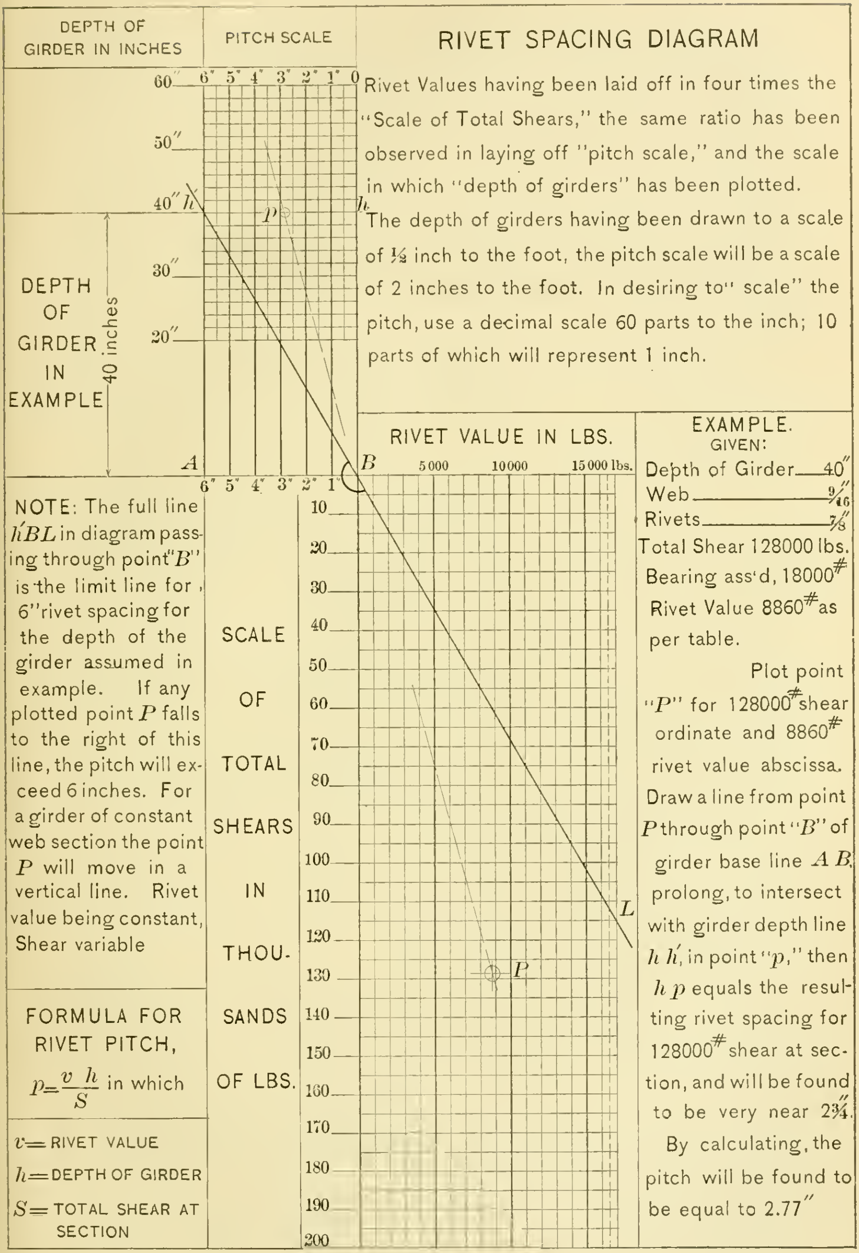
The minimum spacings for rivets are: $2\frac{1}{4}$ ins. for a $\frac{3}{4}$-in. rivet, $2\frac{5}{8}$ ins. for a $\frac{7}{8}$-in., and 3 ins. for a 1-in. rivet.

The panels in which the rivet spacing changes, or should change, are, in the case of concentrated loading, given directly. For a uniform load, or a uniform and concentrated loading combined, suitable panel lengths may be assumed, mostly equal to the depth of the girder. The designer, with a little practice, however, will be able to settle this point without difficulty. The panel lengths also can be determined in such a manner as to obtain in them certain rivet spacings, as illustrated in Fig. 3.

Stiffeners are always provided over the supports, or where concentrated loading occurs, even if the web has been designed to take the greatest shearing stresses for buckling.

As this shearing stress is greatest at the ends, it is taken usually to determine the web thickness. Since, however, stiffeners are always provided at the ends, the writer would recommend, for the purpose of selecting a suitable web thickness, the use of the shear which obtains at a distance equal to the depth of the girder from the ends, or even at a still greater distance.

If the pitch for any panel point has been determined, it is con-



RIVET SPACING DIAGRAM

Rivet Values having been laid off in four times the "Scale of Total Shears," the same ratio has been observed in laying off "pitch scale," and the scale in which "depth of girders" has been plotted.

The depth of girders having been drawn to a scale of ½ inch to the foot, the pitch scale will be a scale of 2 inches to the foot. In desiring to "scale" the pitch, use a decimal scale 60 parts to the inch; 10 parts of which will represent 1 inch.

EXAMPLE.
GIVEN:
Depth of Girder——40"
Web——9/16"
Rivets——7/8"
Total Shear 128000 lbs.
Bearing ass'd, 18000#
Rivet Value 8860# as per table.

Plot point "*P*" for 128000# shear ordinate and 8860# rivet value abscissa. Draw a line from point *P* through point "*B*" of girder base line *A B*, prolong, to intersect with girder depth line *h h'*, in point "*p*," then *h p* equals the resulting rivet spacing for 128000# shear at section, and will be found to be very near 2¾". By calculating, the pitch will be found to be equal to 2.77"

NOTE: The full line *h'BL* in diagram passing through point "*B*" is the limit line for 6" rivet spacing for the depth of the girder assumed in example. If any plotted point *P* falls to the right of this line, the pitch will exceed 6 inches. For a girder of constant web section the point *P* will move in a vertical line. Rivet value being constant, Shear variable

FORMULA FOR RIVET PITCH,

$p = \frac{v\ h}{S}$ in which

v = RIVET VALUE
h = DEPTH OF GIRDER
S = TOTAL SHEAR AT SECTION

Fig. 6.

tinued to the next panel point toward the center, for practical reasons. Theoretically, and as may be seen from the shear diagram and from the method by which the pitch is obtained, the distance from rivet to rivet changes gradually, or abruptly, as does the shearing stress. To realize such constantly varying spacing of rivets in girders would be very impractical and expensive unless performed by an automatically arranged punching machine. In any case, the rivets are never spaced more than 6 ins. apart, and, in case of girders carrying floors, the spacing is recommended not to exceed 4 ins.

Spacing-panels for rivets should always contain an even number of spaces. The usual spacing for rivets should be preferably given in full inches or full and half inches. Quarter-inch fractions, however, are frequently used.

The foregoing method of finding the rivet spacing in web members of plate girders has been compacted in the diagrams, Figs. 6 and 7. Auxiliary tables (Tables Nos. 1, 2 and 3) have been added to give all the necessary data to design the web plates of girders without having to inspect books or tables.

If the analytic method is used, the diagrams and tables will be of advantage in computing shear stresses. The necessary explanations of how to use the diagrams are noted at the proper places. An example is given for finding the rivet pitch for a given total shear of 128 000 lbs. for a $\frac{7}{8}$-in. rivet in a $\frac{9}{16}$-in. web, and for 18 000 lbs. bearing per square inch of rivet diameter.

It may be noted that the points P (see lower part of rivet spacing diagram), for a particular girder, with constant web section, will all be located in a vertical line, since the rivet value remains constant; the shearing stresses only varying along the length of the girder. The shear diagram, for finding the shear per square inch of web area of a given or assumed web, can be used in the reverse manner, that is, to find the necessary total web section for a given or assumed unit shear per square inch and a given total shear.

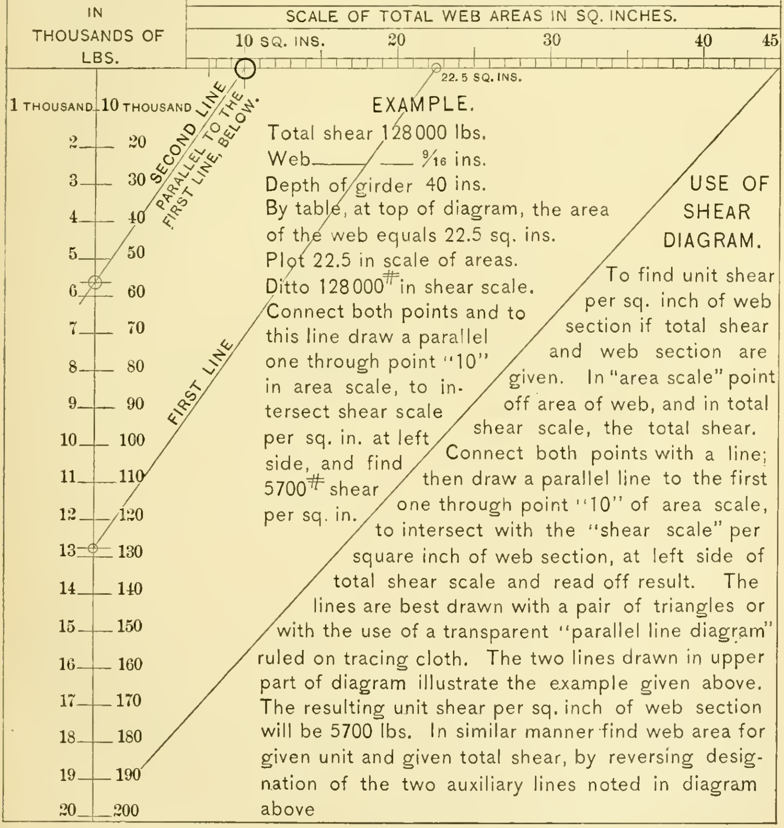
The manner of doing this is given indirectly in the explanation of how to use the shear diagram. By entering the table of web areas, the web thickness will be found with due regard to the assumed depth of the girder.

Allusion will have to be made to the term "depth of girder."

AREAS OF WEBS FOR DEPTHS OF

THICKNESS OF WEB IN INCHES	24	28	30	32	36	40	42	48	50	54	60″
$\frac{5}{16}$	7.5	8.75	9.37	10.0	11.25	12.5	13.12	15.0	15.6	16.87	18.75
$\frac{3}{8}$	9.0	10.5	11.25	12.0	13.5	15.0	15.75	18.0	18.75	20.25	22.5
$\frac{7}{16}$	10.5	12.25	13.12	14.0	15.75	17.5	18.38	21.0	21.87	23.62	26.25
$\frac{1}{2}$	12.0	14.0	15.0	16.0	18.0	20.0	21.0	24.0	25.0	27.0	30.0
$\frac{9}{16}$	13.5	15.75	16.87	18.0	19.75	22.5	23.62	27.0	28.12	30.37	33.75
$\frac{5}{8}$	15.0	17.5	18.75	20.0	22.5	25.0	26.24	30.0	31.25	33.75	37.5
$\frac{11}{16}$	16.5	19.25	20.62	22.0	24.75	27.5	28.86	33.0	34.38	37.12	41.25
$\frac{3}{4}$	18.0	21.0	22.5	24.0	27.0	30.0	31.5	36.0	37.5	40.5	45.0

DIAGRAM FOR SHEAR PER SQ. IN. OF WEB AREA
FOR TOTAL SHEARS UP TO 200000 LBS. AND
TOTAL WEB AREAS OF 45 SQ.INS.



EXAMPLE.

Total shear 128000 lbs.
Web — 9/16 ins.
Depth of girder 40 ins.
By table, at top of diagram, the area of the web equals 22.5 sq. ins. Plot 22.5 in scale of areas. Ditto 128000# in shear scale. Connect both points and to this line draw a parallel one through point "10" in area scale, to intersect shear scale per sq. in. at left side, and find 5700# shear per sq. in.

USE OF SHEAR DIAGRAM.

To find unit shear per sq. inch of web section if total shear and web section are given. In "area scale" point off area of web, and in total shear scale, the total shear. Connect both points with a line; then draw a parallel line to the first one through point "10" of area scale, to intersect with the "shear scale" per square inch of web section, at left side of total shear scale and read off result. The lines are best drawn with a pair of triangles or with the use of a transparent "parallel line diagram" ruled on tracing cloth. The two lines drawn in upper part of diagram illustrate the example given above. The resulting unit shear per sq. inch of web section will be 5700 lbs. In similar manner find web area for given unit and given total shear, by reversing designation of the two auxiliary lines noted in diagram above

FIG. 7.

This term has several distinct and different meanings, relative and specific, all of which must be fully understood and correctly applied.

Generally, and as ordinarily understood, the depth of the girder is that fractional part of the span which constitutes its height, in common parlance, and in most cases is settled upon first and definitely after a thorough consideration of conditions, whether restrictions as to depth and width have to be observed, or whether the designer is at liberty to choose these, according to his best judgment. After the depth, etc., has been assumed in this general way, the other specific depths to be mentioned are derived therefrom as the design progresses, commencing with the flanges.

If, in ordinary building practice, for instance, no restrictions are placed on the depth of girders, it is found (the result being in inches) by multiplying the span of the girder (expressed in feet) by six-tenths, and adding to the product the constant amount, 3 ins. The rate of depth of girder to length of span is, in this instance, one-twentieth plus the constant.

In heavier work the multiplier is eight-tenths, equal to a one-fifteenth rate. In bridge work the proportion of depth to span is increased to from one-twelfth to one-eighth, corresponding to multipliers of 1 and 1.5, respectively.

Having explained the first meaning of the term "depth of girder," the other meanings will now be referred to.

In determining the rivet spacing of the rivets connecting the web plate to the flange angles the depth of the girder is the vertical distance between the horizontal rivet lines located in the vertical legs of the top and bottom chord angles.

If the buckling value of the web plate is concerned, the depth of the girder is the clear distance between the inner edges of the vertical legs of the same angles.

The fourth subdivisable meaning of this term is involved when flange stresses are computed. If these are determined by the ordinary approximate method, the depth of the girder is taken from out to out of flange angles, if cover plates have to be provided to make up the required flange area. If none are needed, the depth is equal to the vertical distance between the centers of gravity of each pair of upper and lower flange angles.

If the exact method of moment of resistance, or, more correctly, that of the section modulus, is selected to determine the cross-section of a plate girder, then we have to introduce into the computation for the depth (no flange plates) the distance "out to out" of angles, as before. With flange plates, take the depth over all the plates; the depth will change wherever a plate is dropped off.

There exists a sixth condition regarding this term, frequently overlooked by younger designers, and of which no mention is made in treatises on applied mechanics, in that the depth "out to out" of flange angles, as a rule, is greater by ½ in. than the depth of the web plate over all. This allowance of ¼ in., at top and bottom, is made to avoid the projection of any part of the web beyond the flange angles. This allowance, therefore, does away with extra work, either shearing the web beforehand, or chipping it afterward, should the angles and web have been required to be flush.

If universal mill plates are specified for the web, some engineers do not demand this allowance to be made. Others insist on having it observed in every instance, as do most all of the mills in their shop practice. For special purposes, however, it may be required that the web shall project a certain amount beyond the backs of the angles; this is the exception to the rule.

Splicing in webs or angles in plate girders, in sizes ordinarily called for in architectural building practice, is not necessary, as universal mill plates for the web are rolled in dimensions from ⅜ in. by 70 ft., up to ¾ in. by 65 ft., and angles on the average run up to a length of from 60 to 75 ft.

In conclusion, the attention of the reader is directed to two noteworthy papers on plate girders. The first, by J. C. Bland, M. Am. Soc. C. E., in the 1887 handbook of the Pottsville Iron and Steel Company. The second*, somewhat more extended in its scope, by Isami Hiroi, C. E., Professor of Civil Engineering in Sapporo College.

To fully complete this paper, and illustrate the graphical method for finding the rivet spacing in plate girders, the writer has chosen for exemplification the problem worked out by Mr. Hiroi, in his booklet, and in which, as regards the determination of the rivet pitch, he has used largely the analytic method of computation. In Fig. 8 will be found all the data requisite to a full understanding of the problem and the steps to be taken to solve it, and to form an opinion as to the comprehensiveness and simplicity of the writer's method. The attention of teachers of structural mechanics is invited to the manner in which the polygon of maximum shear for the rolling or moving loads, has been formed, as fully explained in the "Programme of Example" accompanying the diagram, for determining whether it is not simpler and more readily executed than by the usual method. The difference in rivet spacing, due to assuming one or the other of the meanings of the term "depth of girder" has also been alluded to. It will be seen thereby how easily the rivet spacing can be adjusted to conform to any depth of girder chosen with this method, if otherwise the conditions of the external forces remain the same.

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* Van Nostrand's Science Series, first edition, 1888; second, 1893, revised.

*Programme of Example.**—Single-track standard-gauge deck-girder, 50-ft. span between centers of bed plates, divided into 10 panels, 5 ft. each, for maximum stresses by bending and shears. Depth of girder, "out to out" of angles, 4 ft. $6\frac{1}{4}$ ins. Depth assumed in computation for stresses, in Hiroi's book* and in this example, 4 ft. 6 ins. = 54 ins. Dead load, 490 lbs. per lineal foot. Rolling load, as per train diagram at top of Fig. 8. Maximum wheel load, 12 000 lbs., and, for local shear computation, assumed to be distributed over a sleeper space of 2 ft. End shear due to dead load, one-fourth of 490 x 50 x 2 = 12 300 lbs. Web thickness, $\frac{3}{8}$ in.; rivets, $\frac{7}{8}$ in. diameter. For bearing unit of 14 400 lbs., in $\frac{3}{8}$-in. web, rivet value 4 700 lbs.; shear unit for web, 6 400 lbs. Flange angles, $3\frac{1}{2}$ ins. x 5 ins. x $\frac{1}{2}$ in ; true depth for rivet spacing, 50 ins. (not adopted in this example).

Construct maximum main shear diagram (curve) for rolling load, $E\,F\,C$, as noted. Construct dead-load shear line, $G\,D$, in reference to $E\,F$. Construct local, vertical, shear-component, due to maximum wheel-load (see left lower corner of girder diagram). Construct total maximum shear curve, $M\,L$, as per Fig. 5, up to center of span. Construct girder diagram, using $\frac{1}{4}$-in. scale for the depth. Produce the flange-rivet bevel-lines $V\,l$, $V_a\,l_a$, $V_b\,l_b$, etc., in shear diagram, for each panel point, and draw the rivet-spacing bevel-lines $A\,p$, $a\,p_a$, etc., in girder diagram, and find the rivet spacings $b\,p$, $b_a\,p_a$, etc. Set off, parallel to $G\,D$, the web value $u\,u'$ in shear diagram, computed at eight-tenths of buckling value in Table No. 1, for a $\frac{3}{8}$ x 47-in. web (54 ins. — 2 x $3\frac{1}{2}$ ins.) (see also page 63, Hiroi). Construct, as per Fig. 2,

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* See "Plate-Girder Construction," by Isami Hiroi, C. E., Van Nostrand's Science Series, No. 95, Second Edition. 1893, Pages 32, 38, 39, 62, 63, 79, 81, 83, etc.

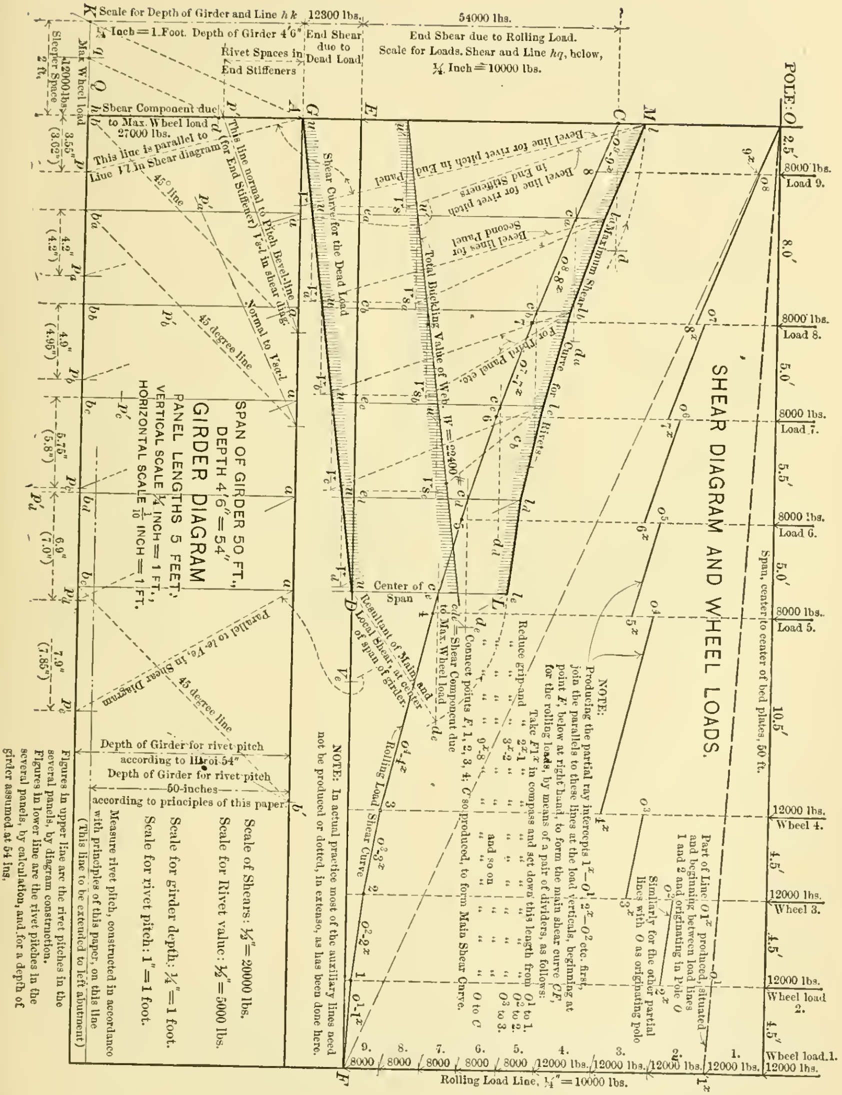
SHEAR DIAGRAM AND WHEEL LOADS.
POLE: O
Span, center to center of bed plates, 50 ft.
Scale for Depth of Girder and Line hk
¼ Inch = 1 Foot. Depth of Girder 4′6″
Rivet Spaces in End Stiffeners
12300 lbs.
End Shear due to Dead Load
54000 lbs.
End Shear due to Rolling Load.
Scale for Loads. Shear and Line hq, below, ¼ Inch = 10000 lbs.
Shear Component due to Max. Wheel load 27000 lbs.
This line is parallel to Line VI in Shear diagram
This line normal to Pitch Bevel-line (for End Stiffener) Ys-l in shear diag.
45° line
Normal to Ys-a.l
45 degree line
Shear Curve for the Dead Load
Total Buckling Value of Web. W = 22400
Bevel line for rivet pitch in End Panel
Bevel line for rivet pitch in End Stiffeners
Bevel lines for Second Panel
For Third Panel etc.
Maximum Shear Curve for Rivets
Center of Span
Resultant of Main and Local Shear, at center of span of girder.
Rolling Load Shear Curve
Parallel to Ve, in Shear Diagram
SPAN OF GIRDER 50 FT., DEPTH 4′6″ = 54″
GIRDER DIAGRAM
PANEL LENGTHS 5 FEET;
VERTICAL SCALE ¼ INCH = 1 FT.;
HORIZONTAL SCALE 1/10 INCH = 1 FT.
Max. Wheel load 12000 lbs.
Sleeper Space 2 ft.
3.55″ (3.62″)
4.2″ (4.2″)
4.9″ (4.95″)
5.75″ (5.8″)
6.9″ (7.0″)
7.9″ (7.85″)
Depth of Girder for rivet pitch according to Haroi 54″
Depth of Girder for rivet pitch 50 inches according to principles of this paper.
(This line to be extended to left abutment)
Measure rivet pitch, constructed in accordance with principles of this paper, on this line
Scale for rivet pitch: 1″ = 1 foot.
Scale for girder depth: ¼″ = 1 foot.
Scale for Rivet value: ½″ = 5000 lbs.
Scale of Shears: ⅓″ = 20000 lbs.
NOTE: In actual practice most of the auxiliary lines need not be produced or dotted, in extenso, as has been done here.
Figures in upper line are the rivet pitches in the several panels, by diagram construction. Figures in lower line are the rivet pitches in the several panels, by calculation, and for a depth of girder assumed at 54 ins.
cd = Shear Component due to Max. Wheel load
Connect points F, 1, 2, 3, 4; C so produced, to form Main Shear Curve.
NOTE: Producing the partial ray intercepts 1x–O1, 2x–O2 etc. first, join the parallels to these lines at the load verticals, beginning at point F, below at right hand, to form the main shear curve CF, for the rolling loads, by means of a pair of dividers, as follows: Take F1x in compass and set down this length from O1 to 1. Reduce grip and set down 2x1 from O2 to 2; 3x2 from O3 to 3, and so on; 9x–8 O to C
Part of Line O1x produced, situated and beginning between load lines 1 and 2 and originating in Pole O
Similarly for the other partial lines with O as originating pole
2.5′ 8000 lbs. Load 9.
8.0′ 8000 lbs. Load 8.
5.0′ 8000 lbs. Load 7.
5.5′ 8000 lbs. Load 6.
5.0′ 8000 lbs. Load 5.
10.5′ 12000 lbs. Wheel 4.
4.5′ 12000 lbs. Wheel 3.
4.5′ 12000 lbs. Wheel load 2.
4.5′ Wheel load 1. 12000 lbs.
9. 8000 8. 8000 7. 8000 6. 8000 5. 8000 4. 12000 lbs. 3. 12000 lbs. 2. 12000 lbs. 1. 12000 lbs.
Rolling Load Line, ¼″ = 10000 lbs.
A G E C M K Q P D F L

FIG. 8.

the stiffener-rivet bevel-lines $V s\, l$, $V s_a\, l_a$, etc., in shear diagram, and produce the corresponding normal lines to these, in girder diagram, giving the rivet spacing-points in stiffeners, as p', $p'a$, etc. The rivet values, $u V$, $u' V_s$, $u V_a$, $u' V_{sa}$, etc., having been laid off at four times the actual rivet value, of 4 700 lbs. (to obtain accuracy), rivet spacings must be measured in a scale having a four times larger denomination than the scale in which the depth of the girder was laid off.

TABLE No. 1.—Total Buckling Values of Webs, $w = \dfrac{10\,000\, d\, t}{1 + \dfrac{d^2}{3\,000\, t^2}}$

Thickness of web in inches.	Depth of Web in Inches.											
	24	28	30	32	36	40	42	48	50	54	60	
$\frac{5}{16}$	25 300	23 750	23 100	22 300	19 700	19 200	18 650	17 200	16 500	15 350	13 850	lbs.
$\frac{3}{8}$	38 600	36 500	36 100	34 700	33 100	31 400	30 400	27 800	27 350	25 700	21 300	"
$\frac{7}{16}$	52 500	51 750	51 500	50 750	47 600	47 000	45 300	42 000	40 750	39 200	36 000	"
$\frac{1}{2}$	68 250	68 500	68 250	67 500	66 000	63 800	63 400	58 800	58 000	53 800	51 000	"
$\frac{9}{16}$	85 500	85 600	85 250	85 400	83 750	83 200	82 800	77 250	74 750	74 750	70 500	"
$\frac{5}{8}$	103 000	103 800	106 000	106 700	107 000	106 700	104 500	102 000	99 500	97 000	92 400	"
$\frac{11}{16}$	105 500	124 750	126 200	128 500	130 050	130 000	129 500	126 500	125 500	121 500	117 000	"
$\frac{3}{4}$	136 000	142 750	147 000	149 500	152 750	154 000	157 800	152 000	151 000	148 500	143 500	"

TABLE No. 2.—Total Buckling Values of Webs, $w = \dfrac{13\,000\, d\, t}{1 + \dfrac{d^2}{3\,000\, t^2}}$

Thickness of web in inches.	Depth of Web in Inches.											
	24	28	30	32	36	40	42	48	50	54	60	
$\frac{5}{16}$	32 800	30 600	30 000	29 000	25 600	25 000	24 300	22 200	21 500	20 250	18 000	lbs.
$\frac{3}{8}$	49 500	47 500	47 000	45 100	43 100	40 750	39 500	36 200	35 600	33 500	27 700	"
$\frac{7}{16}$	68 350	67 300	67 000	66 000	62 000	61 250	58 800	54 750	51 300	51 000	46 800	"
$\frac{1}{2}$	88 750	89 000	88 650	87 900	85 800	83 000	82 500	76 600	75 500	70 000	61 250	"
$\frac{9}{16}$	111 000	112 250	112 900	112 000	111 000	109 500	107 500	102 500	101 200	97 250	91 800	"
$\frac{5}{8}$	132 000	135 000	138 000	138 500	139 000	137 500	136 000	130 250	130 000	126 000	120 000	"
$\frac{11}{16}$	157 000	162 000	164 700	167 000	169 500	169 000	168 500	164 500	163 000	158 500	152 000	"
$\frac{3}{4}$	176 750	186 500	191 000	194 000	198 500	200 000	205 000	197 500	196 500	193 000	186 500	"

TABLE No. 3.—SHEARING AND BEARING VALUES OF RIVETS.

Diameter and area of rivet.		RIVET VALUES.		THICKNESS OF WEB OR PLATE IN INCHES.							
		Single shear.	Shear unit $= \frac{1}{2}$ bea'r.	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$
				Rivet Values for Bearing.							
$\frac{3}{4}$	in	3 310	7 500	3 520	4 220	4 920	5 630	6 330	Bearing values enclosed by		dotted
$\frac{7}{8}$	deci-	4 510	and	4 100	4 920	5 740	6 560	7 380	8 200	9 030	lines
1″	mals.	5 890	15 000	......	5 620	6 560	7 500	8 440	9 380	10 310	11 250
$\frac{3}{4}$	0.75	3 980	9 000	4 220	5 060	5 900	6 760	7 600	are greater than		single
$\frac{7}{8}$	0.875	5 400	and	4 920	5 900	6 880	7 880	8 860	9 840	10 820	hear.
1	1.00	7 070	18 000	5 610	6 750	7 880	9 000	10 500	11 220	12 400	13 450
$\frac{3}{4}$	area	4 420	10 000	4 690	5 630	6 570	7 500	8 440	but less than double		
$\frac{7}{8}$	in	6 010	and	5 470	6 570	7 600	8 750	9 840	10 840	12 300	shear.
1	sq.in.	7 850	20 000	......	7 500	8 750	10 000	11 250	12 500	13 750	The reverse
$\frac{3}{4}$	0.4418	4 860	11 000	5 160	6 190	7 220	8 250	9 280	takes place for values		beyond
$\frac{7}{8}$	0.6013	6 610	and	6 020	7 220	8 430	9 630	10 840	12 040	13 240	these lines.
1	0.7850	8 640	22 000	......	8 250	9 630	11 000	12 380	13 750	15 130	16 500

Vol. XXVI. NOVEMBER, 1900. No. 9.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS AND DISCUSSIONS.

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SOME PECULIAR RAILROAD BRIDGE ACCIDENTS.

By J. I. Boggs, Assoc. M. Am. Soc. C. E.

To be Presented December 19th, 1900.

Several years ago, while the writer was Division Engineer of Maintenance of Way on the Houston and Texas Central Railway, two or three accidents happened to the bridging under his charge, which may possibly be of some historical interest.

The first bridge, Fig. 1, a pin-connected Pratt truss over Richland Creek, of 128 ft. 7½ ins. span, was built by the Phœnix Bridge Company, in the early part of 1887, and, as in all similar work by that company at that time, the posts and upper chords consisted of the old closed Phœnix columns, set into castings at the panel points.

The structure was at the foot of a stiff grade, and while a heavily loaded freight train, moving at a high rate of speed, was passing, a bale of cotton became dislodged and was hurled against the first post, marked "A," Fig. 1, with sufficient force to bend it 13 ins. out of line and knock it clear of the structure, thus leaving the truss with one of its main members missing.

At the time of the accident the structure was entirely covered by

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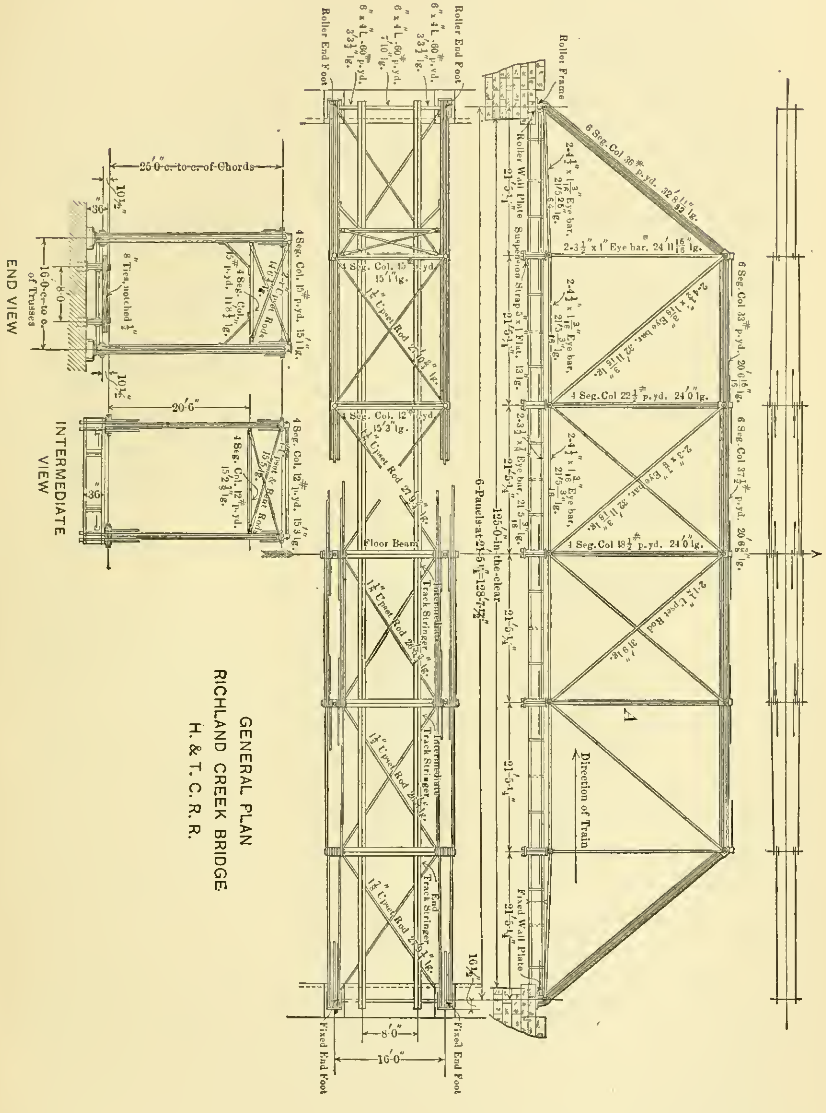

Roller Frame
6 Seg. Col 36# p.yd. 32′ 8 11/32″ lg.
2-4½″ x 1 3/16″ Eye bar. 21′ 5 25/64″ lg.
2-3½″ x 1″ Eye bar. 24′ 11 15/16″ lg.
6 Seg. Col 33# p.yd. 20′ 6 15/16″ lg.
2-4½″ x 1 3/16″ Eye bar. 32′ 11 3/16″ lg.
2-4½″ x 1 3/16″ Eye bar. 21′ 5 3/16″ lg.
4 Seg. Col 22½# p.yd. 24′ 0″ lg.
6 Seg. Col 37½# p.yd. 20′ 6 3/8″ lg.
2-3″ x 1 3/16″ Eye bar. 32′ 11 3/16″ lg.
2-4½″ x 1 3/16″ Eye bar. 21′ 5 3/16″ lg.
2-3½″ x 1/4″ Eye bar. 21′ 5 3/16″ lg.
4 Seg. Col 18½# p.yd. 24′ 0″ lg.
2-1¼″ Upset Rod 31′ 9″ lg.
Direction of Train
Roller Wall Plate
Suspension Strap 5″ x 1″ Flat. 13′ lg.
Fixed Wall Plate
21′-5¼″
125′-0-in-the-clear
6-Panels-at-21′-5¼″=128′-7½″
16½″
Roller End Foot
6″ x 4″ L. 60# p.yd. 33¼″ lg.
6″ x 4″ L. 60# p.yd. 7′ 10″ lg.
4 Seg. Col. 15# p.yd. 15′ 1″ lg.
1¼″ Upset Rod 27′ 10½″ lg.
4 Seg. Col. 12# p.yd. 15′ 3″ lg.
1¼″ Upset Rod 27′ 9¾″ lg.
Floor Beam
Intermediate Track Stringer
1¼″ Upset Rod
End Track Stringer
Fixed End Foot
8′ 0″
16′ 0″
25′ 0″ c. to c. of Chords
10½″
36″
16′ 0″ c. to c. of Trusses
8′ 0″
8″ Ties, notched ½″
4 Seg. Col. 15# p.yd. 15′ 1″ lg.
4 Seg. Col. 15# p.yd. 11′ 8½″ lg.
1½″ Upset Rods
END VIEW
20′ 6″
4 Seg. Col. 12# p.yd. 15′ 3″ lg.
4 Seg. Col. 12# p.yd. 15′ 2½″ lg.
Upset & Bent Rods
INTERMEDIATE VIEW
A

GENERAL PLAN
RICHLAND CREEK BRIDGE
H. & T. C. R. R.

Fig. 1.

the train, weighing approximately 2 500 lbs. per lineal foot. Contrary to all expectations and calculations the bridge carried the remainder of the train, consisting of about twenty loaded cars, across in safety, although the main post was gone.

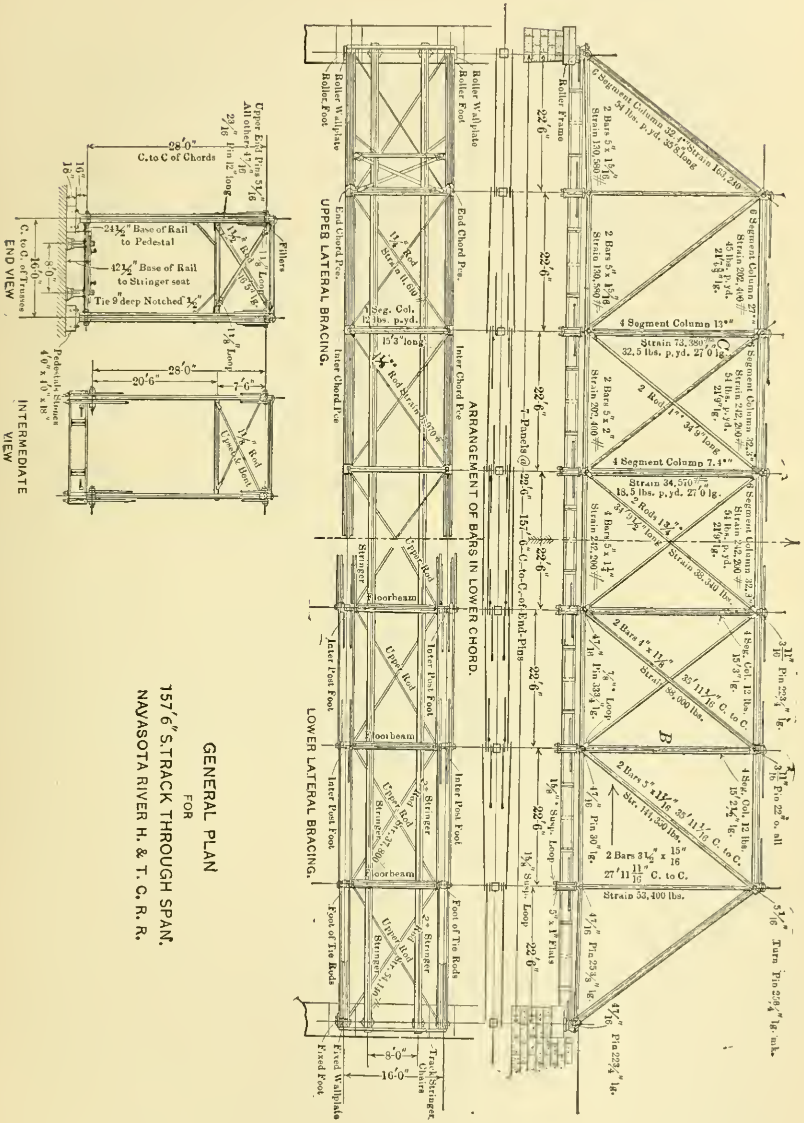
That there was a tremendous bending moment in the upper chord was shown by the following: As quickly as possible a 12 x 12-in. stick of timber, cut to accurate height, was fitted between the upper and lower castings, and a train allowed to pass; as soon as this train had crossed, it was found that the ends of the timber were so badly crushed that it was unfit for further service. A piece of ½-in. plate iron was then inserted between the castings and the timber. This did good service and continued in use until the original member had been taken to the shops, thoroughly repaired and replaced.

In the case of the Navasota River Bridge, Fig. 2, a similar structure, of 157 ft. 6 ins. span, the two posts marked "B" and "C," the former in the left, and the latter in the right-hand trusses, were likewise destroyed by two bales of cotton falling off the same train in opposite directions. Again the train crossed safely, the same steps were taken, and the posts were repaired and replaced.

In both cases the bridges were floored with 8 x 10-in. ties, spaced at 16-in. centers, and had 56-lb. rails.

There was another interesting occurrence at the Trinity River Bridge, a very light Whipple truss, of 130 ft. span, with panel lengths of 12 ft. 6 ins., built in 1877 by the same company. The writer regrets that he has no diagram of this structure. The only idea he can give of its frailty being the statement that the floor beams were only 20 ins. in depth, and the track stringers 7 x 14-in. wooden beams, packed three under each rail. In this instance part of a carload of lumber fell off and struck the first post, permanently bending it about 10 ins. out of the vertical. Several very heavy trains, both freight and passenger, with engines weighing 105 tons, passed over the bridge before the accident to the post was discovered.

The Richland Creek and Navasota River cases are interesting from the fact that it has sometimes been argued that no Pratt truss bridge would stand up under these conditions, and the writer very much doubts if it would if the connections were all rigid. If it did stand it is quite likely that the structure would be so disturbed that a good portion, if not all, would have to be replaced, and this would also



GENERAL PLAN
FOR
157′6″ S.TRACK THROUGH SPAN.
NAVASOTA RIVER H. & T. C. R. R.

ARRANGEMENT OF BARS IN LOWER CHORD.
UPPER LATERAL BRACING.
LOWER LATERAL BRACING.
END VIEW
INTERMEDIATE VIEW
7-Panels @ 22′6″—157′-6″-C.-to-C.-of-End-Pins
22′6″
6 Segment Column 32.4″ Strain 163,240 54 lbs. p.yd. 35′8″ long
6 Segment Column 27″ Strain 202,400# 45 lbs. p.yd. 21′4″ lg.
6 Segment Column 32.3″ Strain 242,200# 54 lbs. p.yd. 21′9″ lg.
4 Segment Column 13″ Strain 73,380# 32.5 lbs. p.yd. 27′0″ lg.
4 Segment Column 7.4″ Strain 34,570# 18.5 lbs. p.yd. 27′0″ lg.
2 Bars 5″ x 1 5/16″ Strain 130,580#
2 Bars 5″ x 2″ Strain 202,400#
4 Bars 5″ x 1 1/4″ Strain 242,200#
2 Rods 1″ 34′9″ long
2 Rods 1 3/4″ 34′9 1/2″ long Strain 38,340 lbs.
2 Bars 4″ x 1 1/8″ Strain 88,000 lbs. 35′11 1/16″ C. to C.
2 Bars 5″ x 1 1/8″ Str. 144,330 lbs. 35′11 1/16″ C. to C.
2 Bars 3 1/2″ x 15/16″ 27′11 11/16″ C. to C. Strain 53,400 lbs.
4 Seg. Col. 12 lbs. 15′3″ lg.
4 Seg. Col. 12 lbs. 15′2 1/4″ lg.
B
C
Roller Frame
Roller Wallplate
Roller Foot
End Chord Pce.
Inter Chord Pce
Inter Post Foot
Foot of Tie Rods
Fixed Wallplate
Fixed Foot
Track Stringer Chairs
Stringer
Floorbeam
Upper Rod
2″ Stringer
8′-0″
16′-0″
28′0″ C.to C of Chords
24 1/2″ Base of Rail to Pedestal
12 1/2″ Base of Rail to Stringer seat
Tie 9″ deep Notched 1/2″
C. to C. of Trusses
Pedestal Stones 4′0″ x 4′0″ x 18″
Fillers
20′6″
7′6″
Upset & Bent

Fig. 2.

probably apply in the case of the floor beam riveted to the post above the chord.

The American pin-connected truss has become famous, the world over, and why American engineers should now incline to the rigid connections of their foreign brethren is, to say the least, remarkable. In the case of the pin-connected truss, where the load to be transmitted is 50 000 lbs., it is known that it must enter the pin, and the pin be designed accordingly, but in the rigid connection, with, say, a shear of 5 000 lbs., we find 10 rivets, two are thrown in for good measure, making twelve all told; these are distributed two, three, two, and so on. Now, how is the 5 000 lbs. distributed? Does each rivet carry an equal portion, or do the first five rivets take the greater part of the stress, producing secondary stresses which will eventually destroy the usefulness of the structure at a much earlier date than would the old pin-connected? At the hazard of being considered ancient, the writer has ventured on the above remarks, and, while not decrying modern methods, he is inclined to the opinion, that there was considerable inherent merit in the designs of our great predecessors, and that the design of later bridges can be seriously questioned; and as the former has stood the test of time, he thinks that it might be as well to hesitate somewhat before venturing too far into new fields.

The writer submits the foregoing as a matter of history and to show the remarkable performances of some of the old designs. He regrets that he has not the time to enter into a mathematical demonstration of cause and effect.

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THE KINZUA VIADUCT OF THE ERIE RAILROAD COMPANY.

By C. R. Grimm, M. Am. Soc. C. E.

To be Presented January 2d, 1901.

The Kinzua Viaduct is on the Bradford Division of the Erie Railroad, and is situated in McKean County, Pa.

The old viaduct was in service for about nineteen years, and has now been replaced by a new steel structure, built under the charge of C. W. Buchholz, M. Am. Soc. C. E., Chief Engineer of the Erie Railroad Company, Mr. M. Strong being the Bridge Engineer. The contractors for the steel work were the Elmira Bridge Company, Limited, Elmira, N. Y.; and the contractors for the erection were Grattan and Jennings, Buffalo, N. Y. The drawings were prepared under the care of E. E. Buchanan, M. Am. Soc. C. E., Secretary of the Elmira Bridge Company. The writer, in his capacity as Engineer of that company, designed the viaduct and also suggested the particular nature of its towers, which, in their construction, form a radical departure from previous practice in viaduct designing. The character of the tower bents is not new, since such forms have often

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been used by structural as well as mechanical engineers; but their application to a railway structure and on a large scale is certainly a novelty.

The design of the viaduct is quite simple, so that it will suffice to give a brief description, but before proceeding to do so, it may be well to state the reasons which led the writer to make his suggestions.

The original problem consisted of the design of towers with stiff members throughout, together with secondary struts and diagonals for the taller towers, lying in a longitudinal vertical plane, coincident with the axis of the structure, and forming a support for the very long members of the wind bracing. A design for the tallest tower, in conjunction with an estimate of its weight, was prepared by the writer, but the weight proved to be excessively great, even after many changes in the design had been introduced. The next step was the substitution of lateral rods for all the longitudinal and transverse diagonals, but this design, too, although calling, of course, for less weight, was soon abandoned. In the early stages of the design the writer entertained no doubt that a tower of nearly 300 ft. in height, and based on the lines described, would never give the desired results, but that, on the contrary, they could be effected by a radical change.

Such tall towers have far too many members to conform with all those advantages which are sought to be realized in a structure. The secondary members, running to a very great weight, and solely designed as a crutch for the protection of the wind bracing, did not appear to the writer as simple means to accomplish a certain purpose. On the contrary, he thought that this purpose could be attained more simply and more directly by building the wind bracing strong enough to take care of itself without the support of a secondary bracing, and likewise, he thought that the tower legs, being the real supporters of the railway, should stand out boldly, instead of looking rather slender and more or less overshadowed by a great mass of bracings. But columns of large size meant a considerable increase in the height of the stories, fewer members to build, a quicker erection and a great reduction in field riveting.

For these reasons the writer suggested two different forms of tower bents, one, as actually built, without transverse diagonals, and the

PLATE XLI.
PAPERS AM. SOC. C. E.
NOVEMBER, 1900.
GRIMM ON KINZUA VIADUCT.

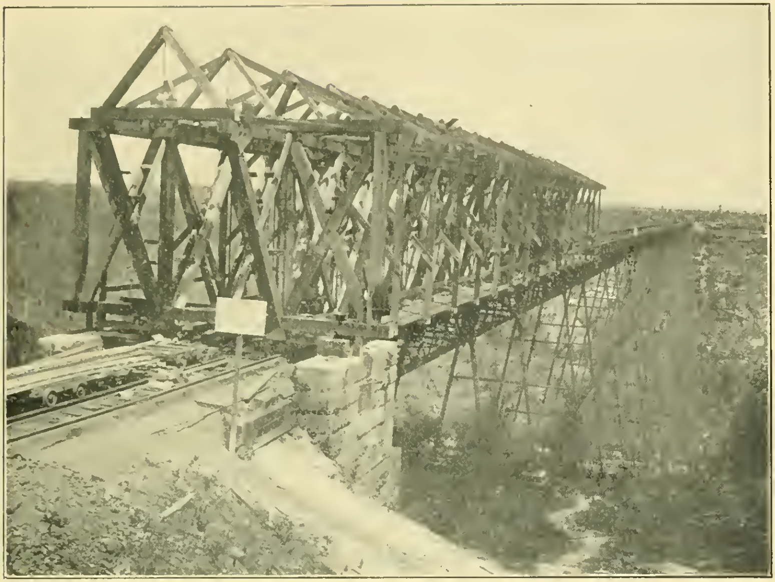


FIG. 1.—THE OLD KINZUA VIADUCT AND TRAVELER.

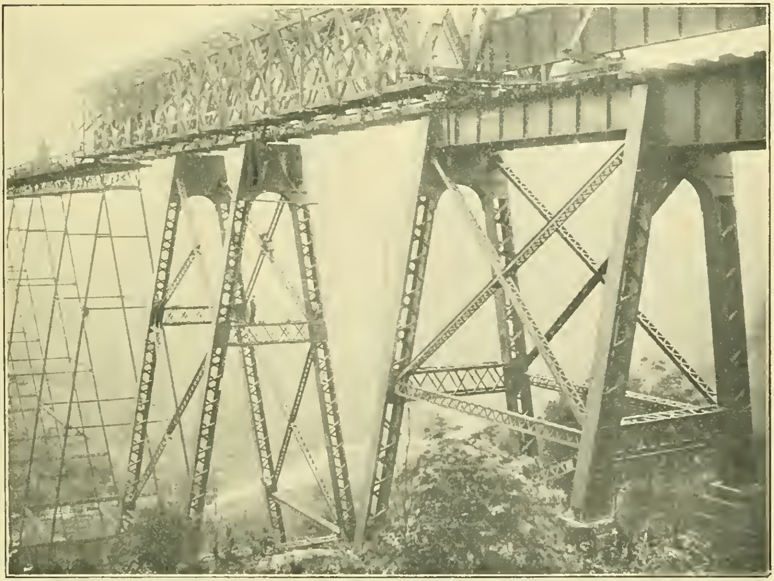


FIG. 2.—NEW KINZUA VIADUCT IN PROCESS OF ERECTION.

other as shown in Fig. 1, in both of which a secondary bracing is dispensed with.

Estimates of the weight of each frame were made, and, although the rejected form of bent has merits well worth full consideration, it may be dismissed at once, since its discussion is outside the province of this paper. The following is a brief description of the work:

The great reduction of the bending moments, due to the wind forces, and a consequent reduction in the weight of the towers, is due to the fact that each bent of the accepted form is practically a triangle, with the principal wind force acting at the top, the sides being rigidly united at the apex by a header, 8 ft. 10 ins. deep, made up of two solid plates as webs, the chords of which are built of angles. These facts, taken in connection with the general appearance of the frame, have favored the adoption of this form of bent.

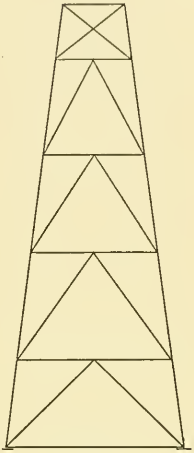


Fig. 1.

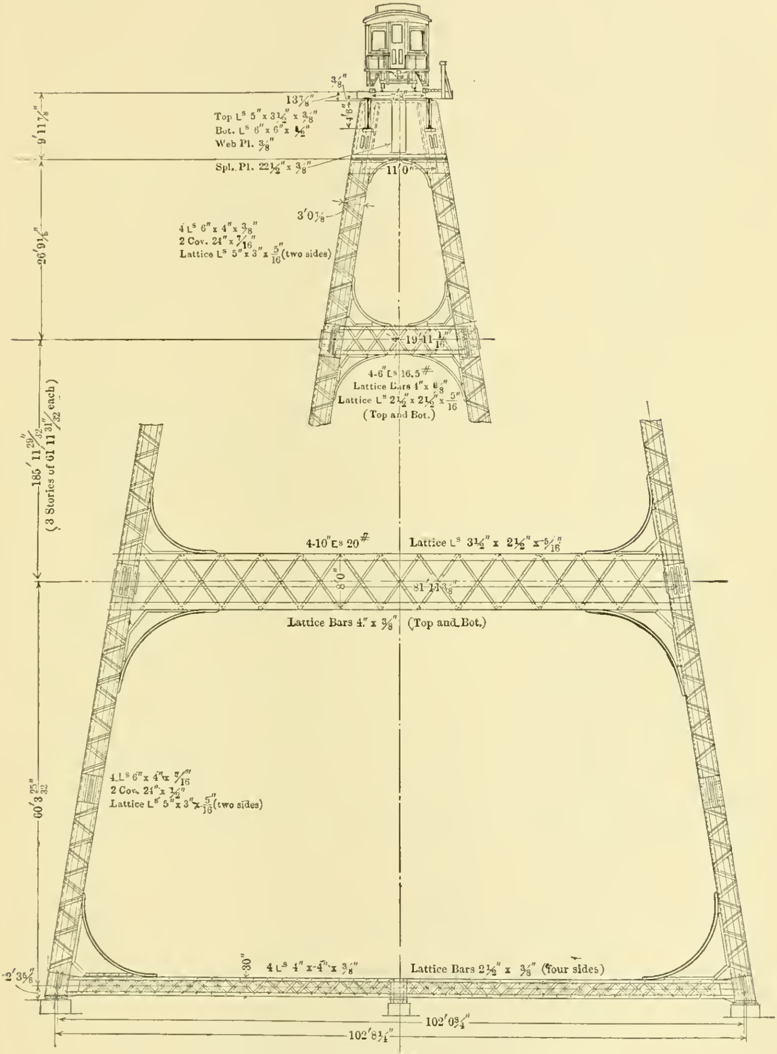
The viaduct, resting on the old piers, is 2 053 ft. long, and carries the railway on twenty towers varying in height from 30 ft. to about 285 ft., from the top of the masonry to the base of the rail, and having a batter of 1 to 6. Fig. 2 is an elevation of the highest bent. As mentioned before, no secondary bracing has been used, but the tallest towers are provided with horizontal adjustable bracings to line up the tower legs during erection. The dimensions, sizes and details of all the towers are the same from their tops downward, or in other words, the dimensions, sizes, etc., for any tower are obtained from the tallest tower by shortening the same from the bottom upward.

The height of the stories, taken transversely, is 62 ft., which means an increase in height of about 100% over that which is common in viaducts, while the height on the longitudinal faces is 31 ft. The columns have no bents at the top, and are composed of two plates, 2 ft. wide, and four 6 x 4-in. angles. They measure 3 ft. 1 in. transversely, and are laced by 5 x 3-in. angle bars. Through each end of the lacing angles, in the two bottom stories of the tallest towers, pass four $\frac{7}{8}$-in. rivets, while only three $\frac{7}{8}$-in. rivets have been used for the three top stories. The bottom struts are deep angle struts, latticed on all four sides, and the higher bents are bolted down at their middle to a pier. The depths of the intermediate transverse struts are 4, 6, 7 and 8 ft., respectively. They have been designed as box lattice girders with stiff web members and brackets at each end, portal fashion. Each chord of these struts is composed of two channels, and their ends, as well as those of the headers, are shaped fork-like so that the columns can pass between the channels of the struts and the web plates of the headers, by which means substantial and very rigid connections are obtained. The single brackets, the legs of which have an average length of 12 ft., have solid webs, and where they connect to the columns, the plates of the latter are stiffened by angles. The longitudinal diagonals form a double system, and are built of two latticed channels connected with plates at their intersection points, and where these diagonals connect with the columns the latter are provided with two diaphragms, about 2 ft. apart. Each tower has two longitudinal bottom struts, but no other longitudinal struts, which make these systems complete without the tower stringers.

The tower legs are bolted to the masonry by two $1\frac{1}{2}$-in. bolts, which had been used in the old viaduct, and which vary in length from 6 ft. to about 10 ft. Provision to meet the effects of changes in temperature is made by pockets, riveted to the headers, in which the ends of the intermediate spans can slide. There are in all twelve freely moving girder ends in the viaduct, which are obtained in the following manner: Each end span is free to move, as also the intermediate span between the two smallest towers at each end of the viaduct, and five pairs of towers are united by having their intermediate spans riveted tightly between them, and, likewise, two groups of three towers each are riveted together. In this way the stresses arising from the braking of trains are reduced. The columns of the three smallest towers at each end of the structure are furnished with sliding plates, while the others are provided with nests of friction rollers.

The fixed ends of the tower legs are placed on the north side of the viaduct, as the wind blows chiefly from that direction.

The spans, Fig. 3, are plate-girder deck-spans, 9 ft. on centers, with the tower spans riveted between the headers. The depth of the tower spans is 4 ft. 6 ins., and the length 38 ft. 6 ins. on centers, and for the intermediate spans the depth is 6 ft. 6 ins. and the length 61 ft. on centers. The chords of the stringers are made up of two 6 x 6-in.



ELEVATION OF HIGHEST BENT KINZUA VIADUCT,
FIG. 2.

angles and one coverplate 14 ins. wide, which runs the full length, both top and bottom, of all stringers. The spans are provided with stiff top and vertical bracings, but bottom bracings are omitted. Other dimensions and sizes, together with the principal details, are shown by the illustrations, so that it will not be necessary to refer to them.

The maximum shearing force in the webs of the plate girders is 4 000 lbs. per square inch cross-section; the maximum flange stress in the intermediate girders equals 12 000 lbs. per square inch, and that of the tower girders 11 600 lbs. The maximum stress in the towers from the supposed combinations of loading does not exceed 14 000 lbs. per square inch, while the elastic limit of the steel used is between 33 000 and 35 000 lbs.

Under the assumed loadings the anchor bolts are never called into action. The shipping weight of the deck spans complete is 638 tons and that of the towers 2 715 tons, making the total weight of the viaduct 3 353 tons. The structure was put into service about the middle of September, 1900.

ERECTION.

The work of erecting the viaduct has been carried on simultaneously from each end by two travelers. These carried the hoisting machinery and spanned a clear space of 160 ft., having an old tower in their middle. In this position the old tower has been taken apart, its material hoisted up and loaded on cars to be run out to the shore end of the structure, whereupon a new tower could be assembled. The work of removing the old viaduct and erecting the new one consumed four months, with a force of about 120 men at 10 hours a day.

SPECIFICATIONS.

The viaduct was built under the regular Erie Railroad specifications for bridges, with certain modifications as to allowable stresses, as follows: Unit stresses for live- and dead- loads were increased 25%, and in the flanges of the girders the whole cross-section was considered as available, but the webs of girders are spliced for flange stress, although not considered in flange section.

Where combinations of wind stresses—bending and direct—with dead-load stresses, or combinations of all the above with live-load

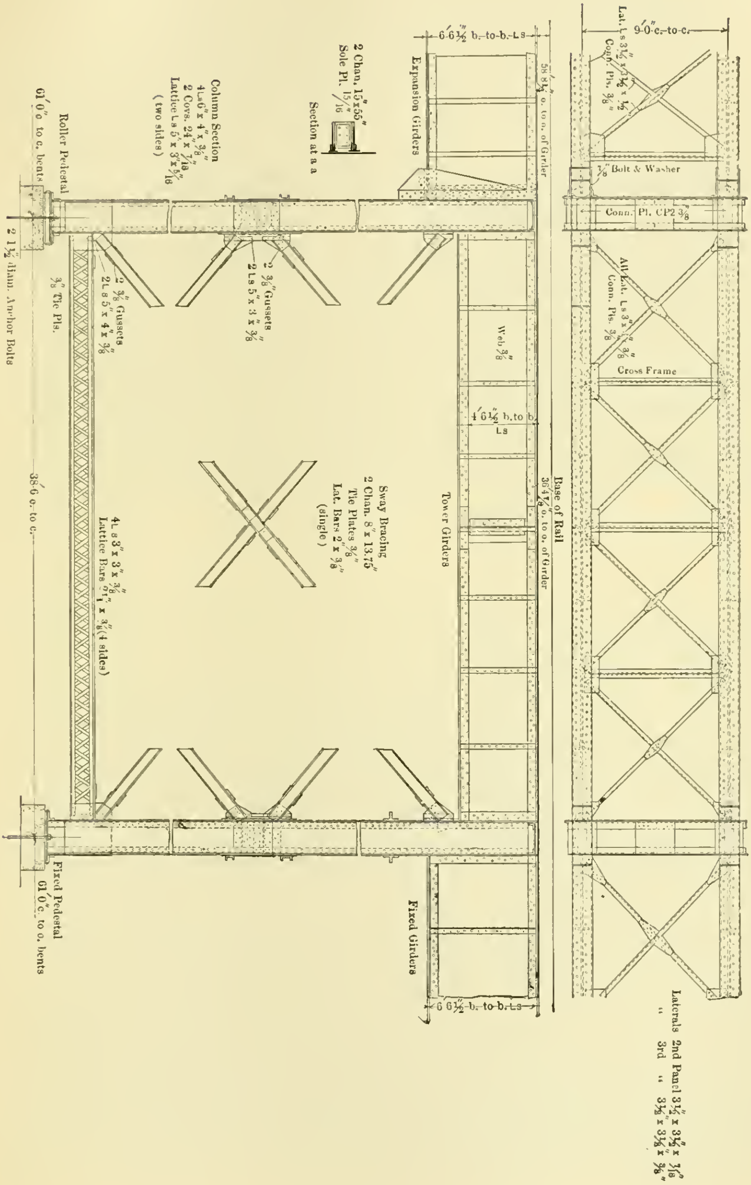

Lat. Ls 3½" x 3½" x ½"
Conn. Pls. ⅜"
9'-0" c.-to-c.
⅞" Bolt & Washer
Conn. Pl. CP2 ⅜"
Alt. Lat. Ls 3" x 3" x ⅜"
Conn. Pls. ⅜"
Cross Frame
Laterals 2nd Panel 3½" x 3½" x 7/16"
" 3rd " 3½" x 3½" x ⅜"
6'-6½" b.-to-b.-Ls
58' 8¼" c. to c. of Girder
Expansion Girders
Base of Rail
36' 4⅞" c. to c. of Girder
Tower Girders
Web ⅜"
4' 6½" b. to b. Ls
Fixed Girders
6' 6½" b.-to-b.-Ls
2 Chan. 15" x 55"
Sole Pl. 15/16"
Section at a a
Column Section
4 Ls 6" x 4" x ⅜"
2 Covs. 24" x 7/16"
Lattice Ls 5" x 3" x 5/16"
(two sides)
Roller Pedestal
61' 0" c. to c. bents
2 ⅜" Gussets
2 Ls 5" x 3" x ⅜"
2 ⅜" Gussets
2 Ls 5" x 4" x ⅜"
⅜" Tie Pls.
2 1½" diam. Anchor Bolts
Sway Bracing
2 Chan. 8" x 13.75
Tie Plates ⅜"
Lat. Bars 2" x ⅜"
(single)
4 Ls 3" x 3" x ⅜"
Lattice Bars 2½" x ⅜" (4 sides)
38' 6" c. to c.
Fixed Pedestal
61' 0" c. to c. bents

FIG. 3.

stresses, or combinations of dead-load stresses with live-load stresses, and traction stresses from the live load exist, the stresses were not allowed to exceed the above by more than 50 per cent.

The wind pressure for the loaded structure was considered to be 100 lbs. per vertical foot of bent plus 30 lbs. per square foot on floor and train. That for the light structure was considered to be 160 lbs. per vertical foot of bent plus 50 lbs. per square foot on floor.

Method of Calculations.

There is no group of stresses which calls for any special mention, except that which is due to the wind forces, since these latter are resisted by bending as well as by direct stresses, and for this reason this group of stresses alone will be investigated.

As far as known, the stresses in frames of the kind under consideration have never before been analytically discussed, and it may be noted that, in order to effect a solution, the problem can be approached from different points of view. The writer preferred a modern analytical method, proceeding from the principle of least work, but, before explaining the method of application of this principle, some general remarks in regard to these tower bents will be given.

In computing the stresses in a bent it is customary to proceed from the supposition that it acts like a cantilever, fixed at the bottom and otherwise free to move; but, while the influence of a force that acts on a bent with articulated joints is confined to a field extending from the point of application of the force to the bottom of the bent, a force that acts on a bent with fixed joints, no matter where its point of application, exercises an influence over the entire frame. A bent of only one story, fixed at the bottom and with fixed joints, will be considered first.

Such a frame partakes of the nature of a hingeless arch, and if quite a general case of loading be assumed, then this frame, like the hingeless arch, is threefold statically indeterminate; that is to say, the values of three unknown quantities must first be found before the stresses can be computed. For this supposed condition of loading none of the points of contraflexure is at the center of the different members, and those of the columns are besides in different horizontal planes. But this state of things is changed, if we have to deal with special loadings, as, for instance, the wind forces, which are supposed to act as concentrated loads at the panel points and in horizontal

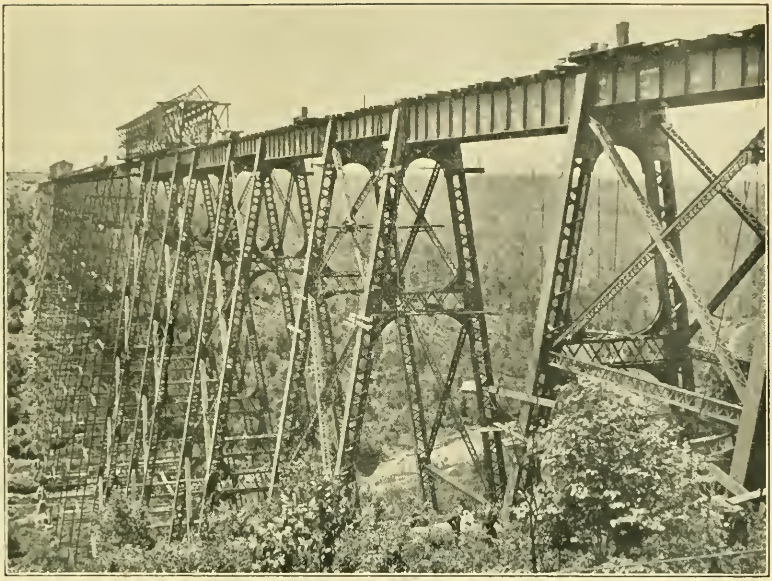


FIG. 1.—NEW KINZUA VIADUCT IN PROCESS OF ERECTION.

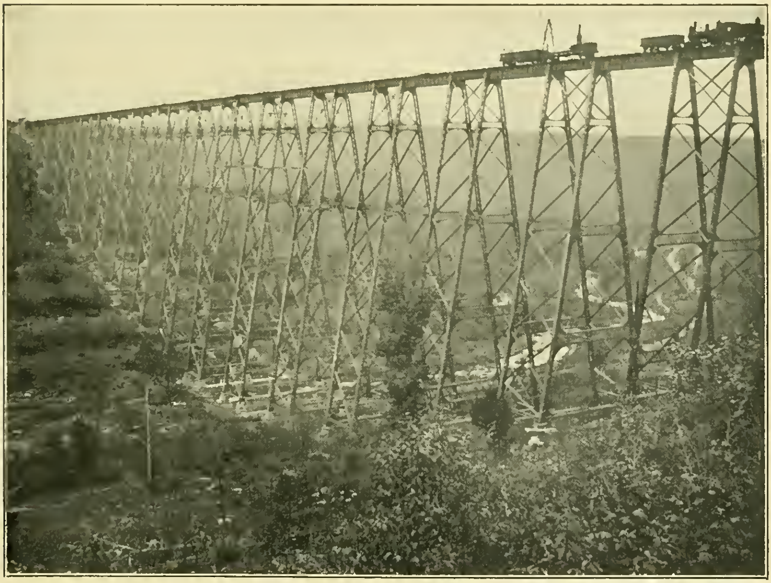


FIG. 2.—THE NEW KINZUA VIADUCT.

planes. In this case the frame becomes singly statically indeterminate. The bending moments of the columns are alike, and the points of contraflexure are on the same level, but not in the middle of these members, which points to the fact that the direct stress in the header equals half of the exterior force, and with the point of contraflexure at the center of the header.

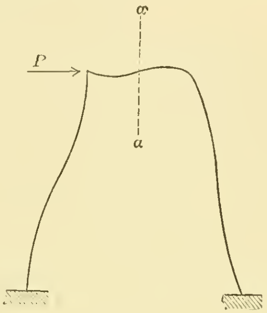


Fig. 4.

In order to illustrate the foregoing statements we pass a cut $\alpha\ \alpha$ through the center of the bent, as indicated in Fig. 4, and apply at this point the unknown vertical force X, Fig. 5, acting upward in the left fragment and downward in the right fragment of the frame. We also apply $\frac{P}{2}$ to each fragment, but a moment need not be applied at the center, because no moment can pass that point. The problem is now to determine the value of the unknown X. In like manner in a two-story bent the direct stress in the header and in the intermediate strut is equal to half of their exterior concentrations, and their points of contraflexure are in the middle, while the bending moments of corresponding columns are alike and their points of contraflexure are not in the middle. The number of unknowns in a two-story bent is therefore 2, and in a bent of n stories the number is n.

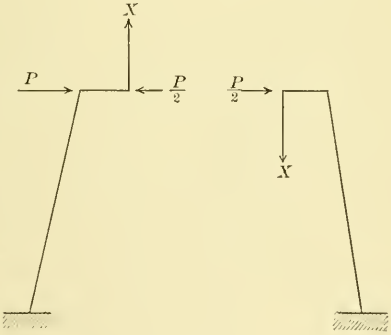


Fig. 5.

The problem can also be stated to consist of finding the locations of the points of contraflexure, because, if these locations were known, it would only be necessary to resolve the resultant of the exterior forces into the reactions, which must pass through the points of contraflexure, and, with the reactions known, the direct stress in any member and the bending moment in any point of the frame is easily computed.

Aside from the margin of safety, provided for by the specifications, judging solely from his previous experience with frames of a similar nature, the writer felt satisfied that this graphical method would answer all practical purposes. In fact, he planned it for practical use, and only his desire to know how much the results thus obtained would vary from the analytical results prompted him to develop an analytical treatment.

The writer made the calculations for a wind pressure of 30 lbs. per square foot on girders and train and 100 lbs. per vertical foot of bent, and for five different bents, varying in height by a regular story of 62 ft., excepting the top story, which has a height of about 31 ft., and the results thus obtained answer perfectly well for the bents in the entire structure. Considering the magnitude of the stresses thus computed, an approximate determination of the effects of a wind force of 50 lbs. per square foot on the girders and 160 lbs. per vertical foot of bent appeared to be justifiable. After these few remarks the application of the principle of least work to the bents will now be shown, but in doing so the reader's familiarity with this principle must be assumed, since a demonstration of its truth is beyond the scope of this paper.

The bents are considered as being under no initial stress. Neglect the small alterations in the lengths of the members and consider bending alone. The principle of least work requires that the work of deformation shall be a minimum, which is expressed by

$$W = \int \frac{M^2}{2\,E\,I}\,d\,x = \text{Min.}$$

In this term $W =$ work of deformation, $m =$ moment of the exterior forces at any point, $E =$ modulus of elasticity, supposed to be constant throughout the frame, and $I =$ constant moment of inertia of a member under consideration. Now, if the work of deformation be a minimum, its partial derivatives, taken successively with respect to the unknowns $X_1, X_2 \ldots\ldots X_n$, treated as independent of each other, must be put each equal to zero. The equations of condition are then as follows:

$$\left.\begin{aligned}
\frac{\delta\,W}{\delta\,X_1} &= \frac{\delta\left[\int \frac{M^2}{2\,E\,I}\,d\,x\right]}{\delta\,X_1} = \int \frac{M}{E\,I}\,\frac{\delta\,M}{\delta\,X_1}\,d\,x = 0 \\
\frac{\delta\,W}{\delta\,X_2} &= \frac{\delta\left[\int \frac{M^2}{2\,E\,I}\,d\,x\right]}{\delta\,X_2} = \int \frac{M}{E\,I}\,\frac{\delta\,M}{\delta\,X_2}\,d\,x = 0 \\
\frac{\delta\,W}{\delta\,X_n} &= \frac{\delta\left[\int \frac{M^2}{2\,E\,I}\,d\,x\right]}{\delta\,X_n} = \int \frac{M}{E\,I}\,\frac{\delta\,M}{\delta\,X_n}\,d\,x = 0
\end{aligned}\right\} \ldots\ldots A$$

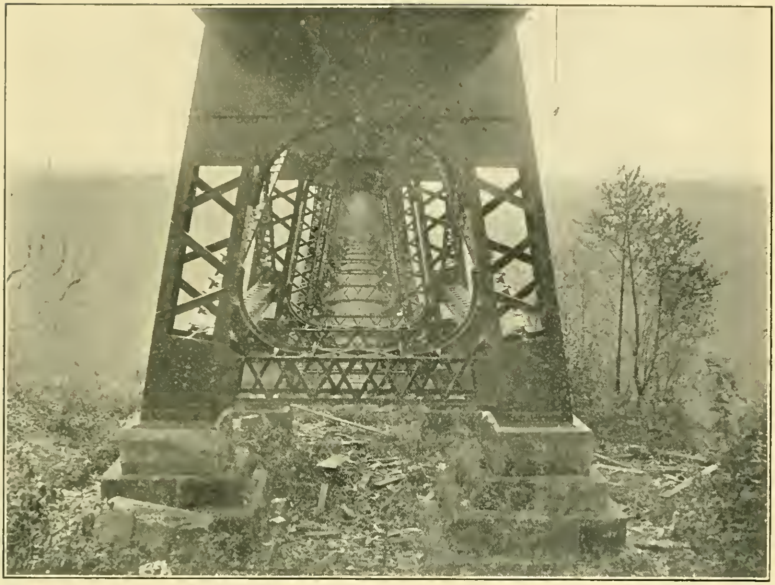


Fig. 1.—Kinzua Viaduct.—Central View Through Top Story.

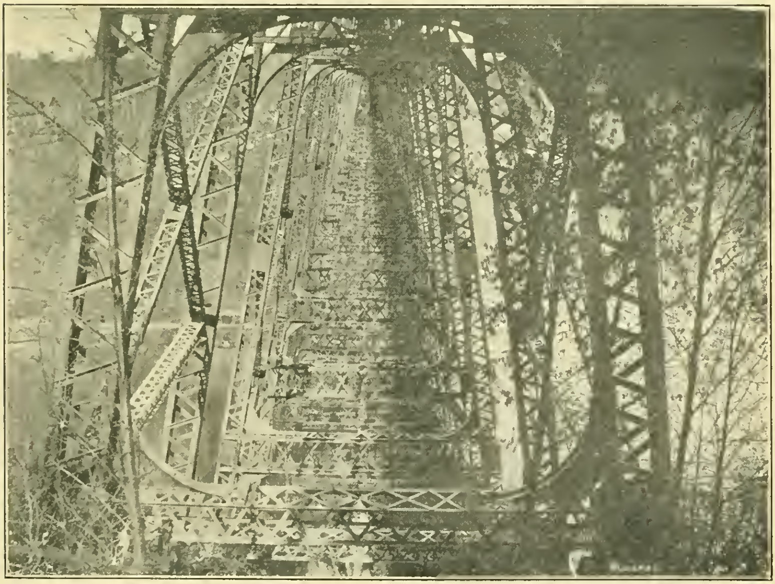


Fig. 2.—Kinzua Viaduct.—Central View Through an Intermediate Story.

The equations "A" are directly applicable to the bents, but it must be noted that the integrations have to be extended over the whole frame, which is equivalent to saying that the integrals, after they have been computed with respect to the individual members of the frame, must all be added together. The reader is now referred to the stress sheets, Figs. 6, 7 and 8, and to the table on pages 1080 and 1081, which the writer prepared for the sake of convenience. The stress sheets and the table contain all the data necessary for the computations, and by the use of the table the different sets of the equations of condition can readily be written down at once; but it should be remarked that each computed integral, as given in the table, must be divided by its corresponding moment of inertia and also by E, the modulus of elasticity. E, being a constant, drops out of the equations, if these are all multiplied by E.

Returning to the one-story bent and referring to the stress sheets, the method of computation is now as follows:

Header:

$$M = - X_5\, r; \frac{\delta M}{\delta X_5} = - r.$$

$$\int \frac{M\, \delta M}{\delta X_5}\, d\, x = \int_{o}^{h = 4.765} X_5\, r^2\, d\, r = 36.06\, X_5.$$

Column:

$$M = P_5 z - X_5\, (h + n\, z); \frac{\delta M}{\delta X_5} = - (h + n\, z)$$

$$\int \frac{M\, \delta M}{\delta X_5}\, d\, x = - \int^{a = 31.16} [P_5 z - X_5\, (h + n\, z)]\, (h + n\, z)\, d\, z =$$

$$- 26760.27 + 1758.54\, X_5$$

The equation of condition becomes now:

$$\frac{36.06\, X_5}{107500} - \frac{26760.27 - 1758.54\, X_5}{10750} = 0$$

and its solution gives: $X_5 = 15.2$ tons. Likewise, the two equations of condition for a two-story bent are found from the table, viz.:

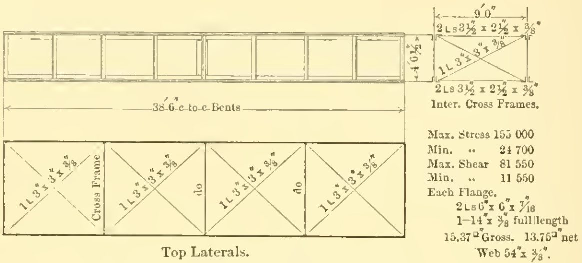
$$\frac{- 26760.27 + 1758.54\, X_5 - 451582.21 + 14735.11\, [X_5 + X_4]}{10750} + \frac{36.06\, X_5}{107500} = 0.$$

$$\frac{- 451582.21 + 14735.11\, [X_5 + X_4]}{10750} + \frac{329.35\, X_4}{5511} = 0$$

The values of the unknowns are: $X_5 = 19.27$ tons and $X_4 = 10.9$ tons.

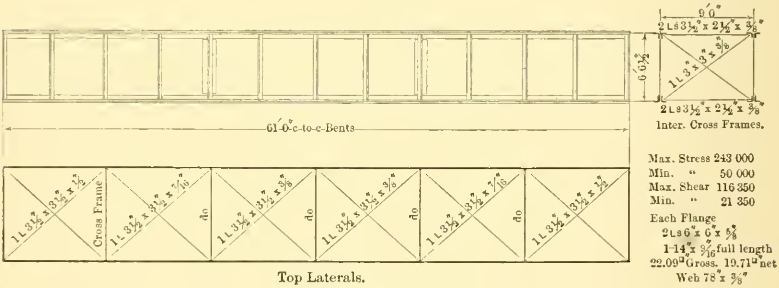
After the unknowns have been determined, it is then easy to calculate the bending moments at every point of the frame.

The direct stresses in the columns $= \mp \sin \alpha \, \Sigma \, P \mp \cos \alpha \, \Sigma \, X$, and they are tension on the windward and compression on the leeward side of the bent, α being the angle formed by the axis of the tower leg and the vertical. The shear on the columns is principally and effectively resisted by the lacing angles.



Assumed Dead Load=1200# per lin. foot of span.

FIG. 6.



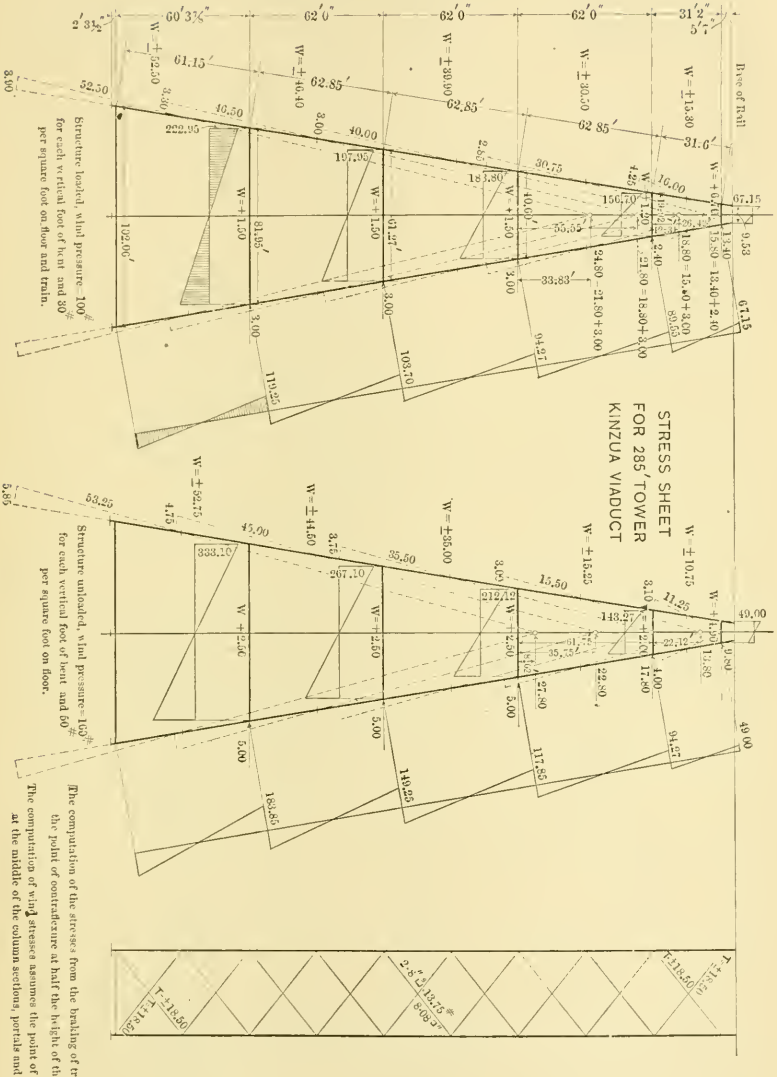
Assumed Dead Load=1400# per lin. foot of span.

FIG. 7.

Bent of 1 story .... $X_5 = 15.2$.
" " 2 stories .... $X_5 = 19.27$; $X_4 = 10.9$.
" " 3 " .... $X_5 = 19.41$; $X_4 = 11.64$; $X_3 = 7.77$.
" " 4 " .... $X_5 = 19.43$; $X_4 = 11.67$; $X_3 = 8.10$; $X_2 = 5.86$.
" " 5 " .... $X_5 = 19.44$; $X_4 = 11.68$; $X_3 = 8.14$; $X_2 = 6.2$; $X_1 = 4.96$.

In the manner just outlined the computations for the five different bents have been made, and, although it was somewhat tedious, it in no wise proved to be a hardship. The structure of the equations of condition is such that those for a four- and five-story bent have been effected by ordinary means, instead of having recourse to the theory of determinants.

The stress sheets show also the direct stresses and bending moments of the highest bent from the wind forces found by graphic


STRESS SHEET FOR 285′ TOWER KINZUA VIADUCT

Structure loaded, wind pressure=100# for each vertical foot of bent and 30# per square foot on floor and train.

Structure unloaded, wind pressure=150# for each vertical foot of bent and 50# per square foot on floor.

The computation of the stresses from the braking of trains assumes the point of contraflexure at half the height of the towers.

The computation of wind stresses assumes the point of contraflexure at the middle of the column sections, portals and headers.

FIG. 8.

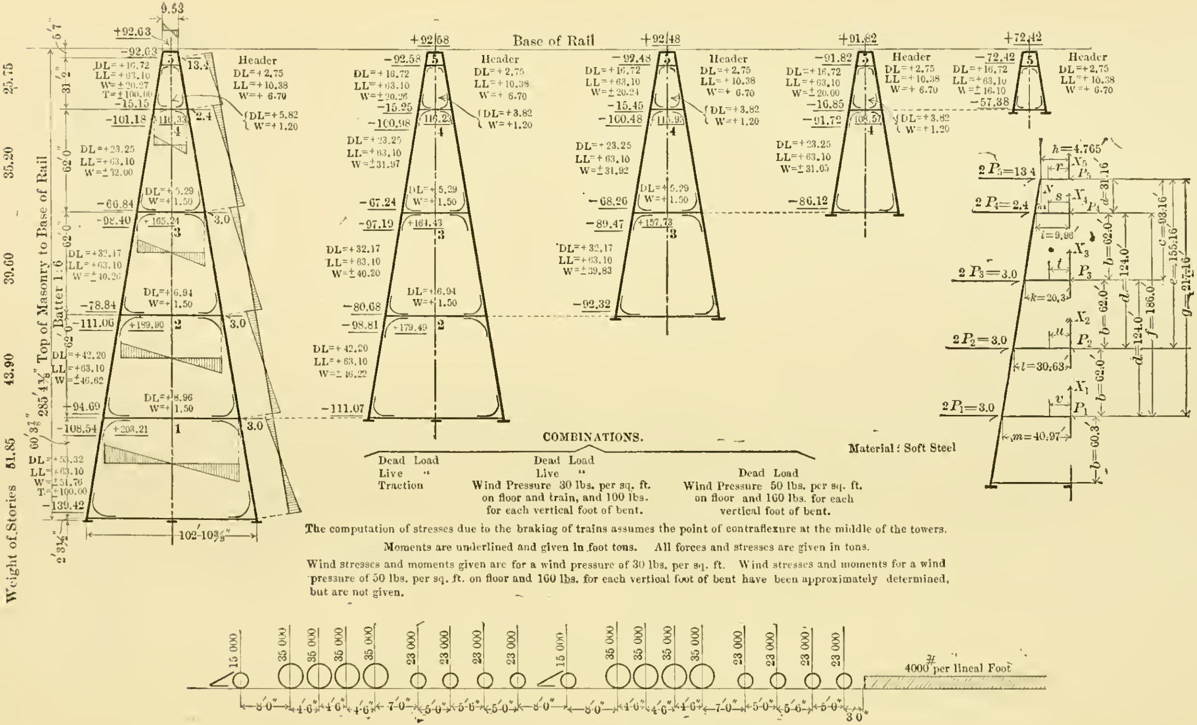
			STRUT "4."	STRUT "3."	STRUT "2."	STRUT "1."
	1st-story column.	Header.	Twin latt. girder.	Twin latt. girder.	Twin latt. girder.	Twin latt. girder.
Sizes.	4 L's 6 x 4 x $\frac{7}{16}$ in. 2 Pl. 24 x $\frac{1}{2}$ in. Latt. L's 5 x 3 x $\frac{5}{16}$ in.	2 L's 5 x $3\frac{1}{2}$ x $\frac{3}{8}$ in. 2 L's 6 x 6 x $\frac{1}{2}$ in. 2 Pl. $105\frac{1}{2}$ x $\frac{3}{8}$ in.	4 6″ U's 10.5 lb. Latt. L's $2\frac{1}{2}$ x $2\frac{1}{2}$ x $\frac{5}{16}$ in. Latt. bars 4 x $\frac{3}{8}$ in.	4 8″ U's 13.75 lb. Latt. L's $2\frac{1}{2}$ x $2\frac{1}{2}$ x $\frac{5}{16}$ in. Latt. bars 4 x $\frac{3}{8}$ in.	4 10″ U's 20.0 lb. Latt. L's $3\frac{1}{2}$ x $2\frac{1}{2}$ x $\frac{5}{16}$ in. Latt. bars 4 x $\frac{3}{8}$ in.	4 10″ U's 20.0 lb. Latt. L's $3\frac{1}{2}$ x $2\frac{1}{2}$ x $\frac{5}{16}$ in. Latt bars 4 x $\frac{3}{8}$ in.
Width and depth out to out	2′ $0\frac{1}{2}$″ x 3′ 1″	2′ $1\frac{1}{4}$″ x 8′ 10″	2′ $4\frac{5}{8}$″ x 4′ 0″	2′ $5\frac{1}{4}$″ x 6′ 0″	2′ 6″ x 7′ 0″	2′ 6″ x 8′ 0″
Moment of inertia	12 356	107 500	5 511	16 692	32 514	43 803
Unknowns		X_5	X_4	X_3	X_2	X_1
Moment M of exterior forces	$P_5\,g + P_4\,f + P_3\,d + P_2\,b\,(P_5 + P_4 + P_3 + P_2 + P_1)\,z - (X_5 + X_4 + X_3 + X_2 + X_1)\,(m + n\,z)$	$-X_5\,r$	$-X_4\,s$	$-X_3\,t$	$-X_2\,u$	$-X_1\,v$
$\frac{\delta M}{\delta X_5}$	$-(m + n\,z)$	$-r$				
$\frac{\delta M}{\delta X_4}$	$-(m + n\,z)$		$-s$			
$\frac{\delta M}{\delta X_3}$	$-(m + n\,z)$			$-t$		
$\frac{\delta M}{\delta X_2}$	$-(m + n\,z)$				$-u$	
$\frac{\delta M}{\delta X_1}$	$-(m + n\,z)$					$-v$
$\int \frac{M\,\delta M}{\delta X_5\,d\,x}$	$-6502866.84 + 128073.93\,(X_5 + X_4 + X_3 + X_2 + X_1)$	$+36.06\,X_5$				
$\int \frac{M\,\delta M}{\delta X_4\,d\,x}$	$-6502866.84 + 128073.93\,(X_5 + X_4 + X_3 + X_2 + X_1)$		$+329.35\,X_4$			
$\int \frac{M\,\delta M}{\delta X_3\,d\,x}$	$-6502866.84 + 128073.93\,(X_5 + X_4 + X_3 + X_2 + X_1)$			$+2788.47\,X_3$		
$\int \frac{M\,\delta M}{\delta X_2\,d\,x}$	$-6502866.84 + 128073.93\,(X_5 + X_4 + X_3 + X_2 + X_1)$				$+9579.00\,X_2$	
$\int \frac{M\,\delta M}{\delta X_1\,d\,x}$	$-6502866.84 + 128073.93\,(X_5 + X_4 + X_3 + X_2 + X_1)$					+22[illegible]23.27 X_1

	5th-story column.	4th-story column.	3d-story column.	2d-story column.
Sizes.	4 L's 6 x 4 x $\frac{3}{8}$ in. 2 Pl. 24 x $\frac{7}{16}$ in. Latt. L's 5 x 3 x $\frac{5}{16}$ in.	4 L's 6 x 4 x $\frac{3}{8}$ in. 2 Pl. 24 x $\frac{7}{16}$ in. Latt. L's 5 x 3 x $\frac{5}{16}$ in.	4 L's 6 x 4 x $\frac{3}{8}$ in. 2 Pl. 24 x $\frac{7}{16}$ in. Latt. L's 5 x 3 x $\frac{5}{16}$ in.	4 L's 6 x 4 x $\frac{7}{16}$ in. 2 Pl. 24 x $\frac{1}{2}$ in. Latt. L's 5 x 3 x $\frac{5}{16}$ in.
Width and depth out to out	2′ $0\frac{1}{2}$″ x 3′ $0\frac{7}{8}$″	2′ $0\frac{1}{2}$″ x 3′ $0\frac{7}{8}$″	2′ $0\frac{1}{2}$″ x 3′ $0\frac{7}{8}$	2′ $0\frac{1}{2}$″ x 3′ 1″
Moment of inertia	10 750	10 750	10 750	12 356
Unknowns				
Moment M of exterior forces.	$P_5\, z - X_5\, (h + n\, z)$	$P_5\, a + (P_5 + P_4)\, z - (X_5 + X_4)\, (i + n\, z)$	$P_5\, c + P_4\, b + (P_5 + P_4 + P_3)\, z - (X_5 + X_4 + X_3)\, (k + n\, z)$	$P_5 e + P_4\, d + P_3\, b + (P_5 + P_4 + P_3 + P_2)\, z - (X_5 + X_4 + X_3 + X_2)\, (l + n\, z)$
$\frac{\delta\, M}{\delta\, X_5}$	$-(h + n\, z)$	$-(i + n\, z)$	$-(k + n\, z)$	$-(l + n\, z)$
$\frac{\delta\, M}{\delta\, X_4}$		$-(i + n\, z)$	$-(k + n\, z)$	$-(l + n\, z)$
$\frac{\delta\, M}{\delta\, X_3}$			$-(k + n\, z)$	$-(l + n\, z)$
$\frac{\delta\, M}{\delta\, X_2}$				$-(i + n\, z)$
$\frac{\delta\, M}{\delta\, X_1}$				
$\int \frac{M\, \delta\, M}{\delta\, X_5\, d\, x}$	$-26760.27 + 1758.54\, X_5$	$-451582.21 + 14735.11\, (X_5 + X_4)$	$-1594211.87 + 40761\ 72\, (X_5 + X_4 + X_3)$	$-3629878.5 + 79998.14\, (X_5 + X_4 + X_3 + X_2)$
$\int \frac{M\, \delta\, M}{\delta\, X_4\, d\, x}$		$-451582.21 + 14735.11\, (X_5 + X_4)$	$-1594211.87 + 40761.72\, (X_5 + X_4 + X_3)$	$-3629878.5 + 79998.14\, (X_5 + X_4 + X_3 + X_2)$
$\int \frac{M\, \delta\, M}{\delta\, X_3\, d\, x}$			$-1594211.87 + 40761.72\, (X_5 + X_4 + X_3)$	$-3629878.5 + 79998.14\, (X_5 + X_4 + X_3 + X_2)$
$\int \frac{M\, \delta\, M}{\delta\, X_2\, d\, x}$				$-3629878.5 + 79998.14\, (X_5 + X_4 + X_3 + X_2)$
$\int \frac{M\, \delta\, M}{X_1\, d\, x}$				

statics as explained before, under the assumption that the points of contraflexure, through which the reactions must pass, are in the middle of each member of the bent.

The forces are all given in tons and the moments in foot-tons. The algebraic sum of the moments around a panel point must equal zero. Roughly speaking, the moments of the struts are about twice as great as those of the columns.

The author made a special investigation, which brought out the fact that the moments of inertia of a group of members may be changed as much as 100% without materially altering the final results.



COMBINATIONS.

Dead Load Live " Traction	Dead Load Live " Wind Pressure 30 lbs. per sq. ft. on floor and train, and 100 lbs. for each vertical foot of bent.	Dead Load Wind Pressure 50 lbs. per sq. ft. on floor and 160 lbs. for each vertical foot of bent.

The computation of stresses due to the braking of trains assumes the point of contraflexure at the middle of the towers.

Moments are underlined and given in foot tons. All forces and stresses are given in tons.

Wind stresses and moments given are for a wind pressure of 30 lbs. per sq. ft. Wind stresses and moments for a wind pressure of 50 lbs. per sq. ft. on floor and 160 lbs. for each vertical foot of bent have been approximately determined, but are not given.

STRESS SHEET; KINZUA VIADUCT

FIG. 9.

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PAPERS AND DISCUSSIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

CANALS FROM THE LAKES TO NEW YORK.

Discussion.*

By Messrs. THOMAS W. SYMONS, ISHAM RANDOLPH and ARCHIBALD SCHENCK.

Mr. Symons. THOMAS W. SYMONS, M. Am. Soc. C. E. (by letter).—Without entering upon a discussion of the general canal proposition, the writer feels compelled to take exception to some of the statements in Mr. Wisner's valuable paper, and particularly wishes to dissent from his fourth conclusion, which is as follows:

> "The decline of traffic on the Erie Canal since 1880, and the failure of the 14-ft. Canadian canals to divert commerce from the lake and railroad lines, indicate that a waterway of less depth than required for the passage of the best type of lake freighters cannot materially modify the transportation rates over existing routes."

The decline of traffic on the Erie Canal is due to very many causes, the principal ones being that it is not in any manner up to date, that the towing is still being done on it largely by horses and mules, and that the business has never been organized and conducted on modern lines. It has been seriously handicapped by the fact that improvements have been undertaken and discussed which would render the old type and size of boats obsolete; rendering it inadvisable as a business proposition for people to build new boats for canal business or to replace those outworn, with the possibility before them of a larger canal in the near future. Mr. Symons.

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* This discussion (of the papers, by Joseph Mayer and George Y. Wisner, Members Am. Soc. C. E., printed in *Proceedings* for October, 1900) is printed in *Proceedings* in order that the views expressed may be brought before all members of the Society for further discussion.

Communications on this subject received prior to December 28th, 1900, will be printed in a later number of *Proceedings*, and subsequently the whole discussion will be published in *Transactions*.

That the traffic on the Erie Canal has declined, it is true, but it would immediately spring up and grow to enormous dimensions if a proper barge canal were built in its place, if legislative restrictions on the capital of operating transportation companies were removed, and if the business were organized in a thoroughly up-to-date manner. It must not be forgotten that if the Erie Canal has stood still, or worse than still, for the last thirty years, the competing railroads have improved their transportation facilities enormously in ways which it is unnecessary to recount here.

But the most palpable error in this fourth conclusion of Mr. Wisner is his acceptance and statement as to the "failure of the 14-ft. Canadian canals to divert commerce from the lake and railroad lines." As a matter of fact, the Canadian 14-ft. canal system has not yet been fully completed, and it has not yet been used by any boats drawing 14 ft., and probably will not be for some time. Considerable work remains to be done in the canals and the St. Lawrence River before this transportation scheme is fully completed. In addition to this, the Canadian government and private parties have only just begun work at Port Colborne and Montreal to prepare for the traffic which they expect to go through this commercial highway formed by the Welland Canal, Lake Ontario, and the St. Lawrence River and Canals. According to the papers, quite a number of boats are being projected and a number are being built to run on this route as soon as it is complete, and Mr. Wisner has certainly jumped at a conclusion which is in no manner justified by the facts and present data. The 14-ft. Canadian canals may be determined hereafter to be failures, but it certainly has not been proven yet, in advance of their completion.

His premises being entirely in error, it follows that his conclusion "that a waterway of less depth than required for the passage of the best type of lake freighters cannot materially modify the transportation rates over existing routes" is unfounded and unjustifiable. In fact, even granting the premises, the conclusion is by no means justifiable. The barge canal proposed for the Erie Canal route has a capacity for boats four times the size of those now in use. To say that they cannot materially modify transportation rates is just as absurd as it would be to say that 8 000-ton steamers on the Lakes cannot materially modify rates suitable to 2 000-ton steamers.

To aid him in his contentions, Mr. Wisner is willing, apparently, to stand sponsor for the statement that in the case of wooden barges and steel barges of the same size and model, the power required to tow the wooden barges is about twice that required for towing steel barges, and that "the cost for towing per ton-mile for the wooden barge is about double that for the steel." This, he states, is based

Mr. Symons. upon some experiments in towing by Captain C. V. Suppan, Chief of the Steam Navigation Service on the Danube. This alleged fact in regard to the difference in the cost of towing steel and wooden barges is so contrary to common sense and experience that it is difficult to understand how an engineer of standing would be willing to use it in an argument in favor of anything. The only difference there could possibly be would be in the skin friction on the outside of the boat. Assuming that the steel boat and the wooden boat were in equally good condition, the difference in the amounts of this skin friction would necessarily be very slight. This is one of the reasons why Mr. Wisner, in his comparative tables of cost of transportation, insists upon the transportation through the barge canal being done in expensive steel vessels, instead of cheap wooden ones. As a matter of fact, one of the strongest arguments in favor of the barge canal, following the general route of the Erie Canal, is that business upon it can be done in cheap light wooden boats, as these boats would not, at any part of the route, be subjected to the storms which prevail at times on the Great Lakes.

Mr. Wisner gives 4½% as the rate of insurance on a fleet of barges operating on the canal. As a matter of fact, the prevailing rate is 2% for steamers and 1% for ordinary boats, making the average insurance rate on a fleet of one steamer and three plain barges less than 1½%, or less than one-third of the amount stated by Mr. Wisner. He has also increased the cargo insurance in some unexplained manner.

By swelling the cost of the necessary boats for operating on the canal in an entirely unnecessary manner, which largely increases the charge for insurance, interest, and deterioration, Mr. Wisner makes his showing favorable to the ship canal.

The steel boats estimated on by Mr. Wisner would be able to navigate the open Lakes as the Cleveland steel boat fleets are doing today, and could run between the Lakes and the sea in competition with the large steamers on the proposed ship canal, and because of their much lower cost per ton of carrying capacity (about one-third), and lower operating expenses, could furnish transportation cheaper than could the large steamers.

Mr. Wisner also predicates his findings on the lake ship going to New York and getting as quick dispatch, or nearly as quick, as it gets at the Lake ports. Now, this cannot be admitted as a reasonable probability. The only way in which it could get a quick dispatch would be to go to an elevator and discharge its cargo and return with little or no cargo. This would mean another handling of the cargo in New York and an added expense of about as much as the total cost of transportation on a barge canal. The conditions under which business is done in New York are such as to preclude the reasonable probability of a lake ship delivering its cargo into a foreign-bound ship

Mr. Symons.

directly, except occasionally. Nearly all the foreign-bound commerce of New York leaves the port as berth cargoes in the large ocean liners. These ships do not leave their docks, freight has to be brought to them, and there is not room at the dock for the ocean ship and the lake ship, while there is room for the canal's boats and the necessary means of transfer, such as floating elevators, etc. To get anything like the dispatch, at the Port of New York, on which Mr. Wisner figures, would require a very complete upheaval and reversal of the methods of doing business in this great port.

There would certainly be serious delays in the ordinary transaction of business, in getting rid of the cargo of a great ship, which delays could only be obviated by going to large expense in extra handling of the cargo.

Even if the port delays to the barges of a barge canal were as great in New York as the delays to the ship, these delays would not be so serious, as the cost per ton capacity for the barges is very much less than the cost per ton capacity of a great ship, and the operating expenses of the barges are very much less than the operating expenses of a ship, either moving or in port.

There are decided reasons for believing that it would be more convenient, and better for commerce, to have nearly all the western products arrive in New York in lots of about 1 000 tons, in place of having them arrive in lots of 6 000 to 10 000 tons. Nearly all our exports are shipped as berth cargoes in vessels carrying diversified loads, not more than 10 to 15% being shipped in full cargo lots. A cargo of 8 000 tons arriving in eight different loads would go to eight different ships and be transferred, as is the custom now, directly into the ship without its leaving its own berth. The advantages of this in economy and time saving are obviously very great. That it is sometimes more advantageous to divide a large amount of freight into several lots than to carry it all in one, is exemplified in the transportation of coal by water along the Atlantic seaboard. The enormous business of transporting some 30 000 000 tons per year is practically all done in barges of 1 000 to 2 000 tons, three or four of them being towed by one tug. The business of transporting this coal was formerly done in single steamers and sailing vessels, but the tow barge system has supplanted this method almost entirely, and the writer cannot but regard it as a lesson fraught with very great value to any student of the problem of connecting the Great Lakes with the ocean by a water route.

The data furnished by Mr. Wisner is not at all sufficient to prove that the Great Lake freighters could with safety make a speed of 8 miles per hour in the canal proposed by the Board of Engineers on Deep Waterways. There is much to be said on the other side. The fact that boats habitually pass through the short straight St. Clair

Mr. Symons. Flats Canal at a speed of 7 to 11 miles per hour is not conclusive that it would be safe to maintain this speed with full-sized ships in a comparatively long canal, with more or less curvature, and rocky bottom and sides. If the ship canal has a commerce upon it in large ships sufficient to justify the enormous expense to be incurred in building and maintaining it, it must necessarily be fairly well crowded with boats at all times, day and night, in windy and stormy weather as well as quiet and pleasant weather, and under all circumstances. The writer cannot conceive of these ships being driven at a speed of 8 miles per hour and meeting and passing other ships without picturing to himself very great danger of accidents.

Experience demonstrates that accidents are bound to occur to ships navigating such a narrow channel, and that it will be necessary for them to move slowly and with the utmost caution. Any accident which leads to the sinking of a ship in such a narrow canal might, and probably would, in many cases completely block the canal until the ship could be raised and gotten out of the way. During the season of 1899 there were three incidents in the history of transportation on the Lakes which illustrate this danger and the serious consequences which are likely to be incurred through an accident. In the early part of September, 1899, one of the Great Lake boats, the *Douglas Houghten*, laden with ore, broke her steering gear, and went aground in the channel of the St. Marys River. In sinking she swung around across the channel and completely blocked it. It took five days of great effort to get this vessel afloat and out of the channel, and in the meantime 332 vessels were blocked and unable to get by. This caused a great loss to the Lake carrying interests, probably over $500 000.

In the latter part of November another blockade of the St. Marys River Channel occurred, due to a collision in which three vessels, two steamers and a tow barge, were mixed up and stranded, and this caused a delay of nearly four days to some 167 vessels, and involved a very great loss.

In the early part of December a tow barge went aground in the channel leading to the St. Clair Flats Canal, blocking the canal for nearly two days and delaying 35 vessels.

Besides these greater accidents, delaying many ships, there are constantly being reported other accidents of a less serious character in these inter-lake channels, such as the sinking of individual vessels, collisions and damage, the stranding of vessels, etc., due to breaking of steering gear, mistaken signals, or boats taking a sheer. Besides, there is the likelihood of accidents to vessels at the locks themselves, causing detentions and blockades.

There is no getting over the fact that the home and place for large ships is in the wide free waters, and that when they enter the narrow waters they are subject to grave dangers, and must move with extreme caution. So great are these dangers on the narrow channels of 300 to 400 ft. width connecting Lakes Erie, St. Clair, Huron and Superior that the shipping interests of the Great Lakes are making strenuous efforts to get the Government either to widen them to 600 or 800 ft., or to build duplicate channels, one to be used by up-bound and one by down-bound vessels. Mr. Symons.

It does not do to shut our eyes to the perils of great ships in narrow channels. In spite of all precautions, such accidents are likely to happen in narrow channels traversed by ships of 7 000 to 10 000 tons capacity. The longer the channel, the greater is the likelihood of accident, and it is easy to imagine that in a ship canal, from Lake Erie to Lake Ontario, and from Lake Ontario or the St. Lawrence River to New York, such accidents, blockades and detentions would be of frequent occurrence, if used by many vessels. These would all tend to reduce greatly the average speed attainable in the canal. Of course, accidents and detentions are likely to occur on a small canal also, but, owing to the greater ease with which the smaller locks and boats can be managed, the dangers here are not so marked; besides, the results of accidents on a small canal are not so likely to be disastrous as in the case of a greater canal and larger boats. It is a much easier and quicker matter to lighter a small vessel carrying a few hundred tons than it is to do so with a great freighter carrying several thousand tons.

There is another point of view from which this problem must be looked at, and which should receive very serious consideration. The canal, if built, will be built by the United States at a cost of about $200 000 000. If built by the United States the benefits should all accrue to the United States, but would they? It is the writer's very decided opinion that they would not. If a ship canal be built from Lake Erie to New York by the Ontario-St. Lawrence-Champlain route it would be more apt to redound to the disadvantage of American commerce than to its advantage. Such a ship-canal route would follow down the St. Lawrence until within about 50 miles of the seaport of Montreal. It would then branch off to New York, which would be reached only after traversing some 350 miles of canal, lake and river, and when at New York, commodities destined for most foreign markets would be further away from these markets than they were when they left the St. Lawrence. Such a canal would be of some benefit to our local and strictly domestic business, but it would just as certainly be a detriment to our inbound and outbound foreign commerce, tending strongly to take it away from New York and our other North Atlantic cities and build up the commerce of Montreal. Of course, to reach Montreal, Canada would have to add a short section to our ship canal, but this she would certainly do, and then it would be inconceivable that grain, lumber, iron ore, manufactured steel or other articles destined for foreign markets, reaching within 50 miles of Montreal, would

Mr. Symons. retrace their steps through 350 miles of contracted waterway back to the Port of New York.

The same is true, though to a somewhat less extent, in regard to the ship canal projected by the Oswego-Ontario-Oneida-Mohawk route. If the Great Lake freighters, carrying from 7 000 to 10 000 tons of produce, should go into Lake Ontario, they could continue on down the splendid waterway of Lake Ontario and the St. Lawrence River as far as Prescott and Ogdensburg, only about 120 miles from Montreal, and then transfer into 2 000 or 3 000-ton barges to be taken through the Canadian canals to Montreal. All foreign-bound commerce would undoubtedly take this course rather than the route from Oswego to New York through 320 miles of contracted and dangerous waterway with its 590 ft. of lockage. It is altogether certain, too, that in this event Canada would soon enlarge her St. Lawrence canals so as to permit the Great Lake vessels to run directly to Montreal, and the resultant benefits, in that event, would be far greater to Canada than to the United States.

Whatever canal is built should be so located that its benefits would only accrue to the United States, and there is only one canal route between Lake Erie and the ocean of which this is true, and that is along the line of the present Erie Canal. This route is not available for a ship canal, but is available and well suited for a barge canal, and is the only route which should ever be considered by the people of the United States.

The point made by Mr. Wisner against the barge canal, that it could only be fully and properly utilized by the organization of large transportation companies to operate boats on the Lakes and canal with elevators at Buffalo, and that these transportation companies and lake and rail lines would probably combine to maintain rates and thereby destroy the benefits from such a canal, is not, in the writer's opinion, well taken. Such a canal would be free to any number of transportation companies, just as free as the Lakes themselves, and while such a combination might be made, it is also equally probable that in that event other companies would be organized and do business at the lowest profitable rates. The charge of a possible combination to maintain rates would lie almost as well against the ship canal advocated by Mr. Wisner as against the barge canal. In fact, in some respects it would lie more strongly, for it would take less capital to break into a barge canal combination than into a ship canal combination.

Mr. Wisner says:

"Since 1880, when the traffic on the Erie Canal reached a maximum, the rate per ton-mile on the railroads from the Lakes to the seaboard has been nearly double that on the Erie Canal, yet during that time the business on the canal has diminished one-half, while that on the railroads has nearly trebled," etc.

Mr. Symons.

While it may be true that railroad freight rates are double those on the canal, if there be included all kinds of freight carried, and all the year round, it is not true if there be included only the heavy coarse freight ordinarily carried on the canal, and during the period of canal navigation. For many years the canal rates and railroad rates on grain, etc., have very closely approximated to each other during the period of canal navigation, the railroad rates going up at the close of this period. As an illustration it is to be noted that the prevailing rate of 3 cents per bushel, which the railroads have been charging all summer, has just been lifted by the railroad combination to 4 cents, an arbitrary increase of 33⅓%, to take effect November 1st, about the close of the season of canal navigation.

The writer is glad that he can so completely agree with Mr. Wisner in one respect, and that is in his belief that a canal for deep sea ships of 30 ft. draft is not advisable or justifiable. The writer investigated this matter and reported to this effect to the General Government in 1897. He has not yet seen reason to doubt the correctness of the conclusions reached in that report—that there is one type of vessel best suited for use on the ocean, another on the Lakes, and another on narrow canals and waterways; that economy of transportation demands that the vessel be suited to the waters which it traverses, and that no single type of vessel has been, or probably will be, devised, which is suitable to all three or any two of the waters mentioned. He also cordially agrees with Mr. Wisner that the depth to be aimed at for the inter-lake channels and Lake harbors should be limited to that suitable for vessels of 20-ft. draft.

Mr. Wisner and others who advocate a ship canal, lay great stress on its influence in expanding the ship-building industries of the country and "restoring the Merchant Marine of the United States in foreign trade." The writer is unable to see much in this argument. Ships are going to be built on the seashore and on the Lakes just as fast as they are needed, and ships of the same character will cost nearly the same in one place as another. As an instance of this it may be mentioned that a ship of Canadian canal size has just been launched in Buffalo, destined for ocean trade, while at the same time the City of Buffalo is having a large steel fire tug built on the seacoast, the contract for the latter having been awarded after full competition. The mere transference of an industry from one section of the country to another is not in itself a benefit for which the whole country should be called upon to pay a large sum of money.

The foregoing is intended as an answer to a good deal that appears in Mr. Mayer's interesting, but rather transcendental, paper. Some of his theoretical deductions are based on entirely erroneous data. For instance, he bases some of his theories on an amount of tonnage tributary to a ship canal that is far beyond any reasonable probability

Mr. Symons. at any time in the near future. If he were more familiar with the business of transportation on the Lakes he would know that the total tonnage passing through the Detroit River and the Sault Ste. Marie has little relation to the amount of tonnage that would pass through a ship canal from Lake Erie to the sea. The Detroit River and Sault Ste. Marie tonnage is made up principally of coal, ore, lumber and grain. Practically none of the coal would be apt to pass through the ship canal, but little of the ore, while possibly half of the lumber and two-thirds of the grain might be conceived as using the canal. Mr. Mayer's estimate of 36 000 000 tons as a reasonable amount of tonnage on which to base his estimate is far beyond reason. Even Mr. Wisner, strong advocate of the ship canal as he is, only uses 15 000 000 tons in his estimates. It is nearer the mark, for some years to come, to figure on 10 000 000 tons, with a possible increase to 15 000 000 or 20 000 000 tons in the not distant future. With an annual cost of about $9 000 000 and a tonnage of 36 000 000, Mr. Mayer computes an interest and maintenance charge of 25 cents per ton. With the tonnage reasonably to be expected, this would be increased to 90 cents, gradually diminishing to perhaps 50 or 60 cents. And it must not be overlooked that if the tonnage approaches anywhere near Mr. Mayer's 36 000 000, the alternative suggested by him of additional locks and facilities must be met, which will largely increase the interest and maintenance charges. At the Sault Ste. Marie there are now three locks: The American Weitzel lock, 60 x 515 ft.; the American Poe lock, 100 x 800 ft., and the Canadian lock, 60 x 900 ft. The tonnage passing through them all is something like 25 000 000 tons per annum. The American locks are now at times taxed to their full capacity to take care of the tonnage demanding passage, and it is one of the strong demands of the Lake-carrying interests that a new lock, larger even than the Poe lock, be built to accommodate the traffic. It is understood that the Board of Engineers on Deep Waterways proposes a single lock on the line of its ship canal about 60 x 600 ft., about half the size of the Poe lock at the Sault Ste. Marie, and only large enough for the passage of one large steamer at a time.

Experience at the Sault would indicate that as the Lake carrying business is distributed throughout the year, such a lock cannot be expected to handle much over 10 000 000 to 15 000 000 tons annually.

In regard to the number of trips on which the estimated cost of transportation is based, the writer has now only this to say:

In the transaction of a transportation business by great vessels on such a ship canal as advocated by Mr. Mayer and Mr. Wisner, there is a vast difference between a reasonable probability and a theoretical possibility. The writer conceives that his estimate of 10 trips per year between Buffalo and New York is the first, and the estimate of 16 trips between Chicago or Duluth and New York is the second.

Isham Randolph, Esq.* (by letter).—The writer lacks the data upon which to base a discussion sustaining his preconceived ideas in favor of a channel deeper than 21 ft. This question passes beyond the problem of construction and cost into the realm of political economy, and statesmen must decide how much the Nation should expend upon a channel designed to connect the mid-continent with the World's ocean highways and give the producers and consumers of the Middle West and Northwest access to the World's markets upon terms nearly equal with those of the Atlantic States. Of one thing, however, the writer feels sure, that any plan for connecting the Great Lakes with the Atlantic Coast should be executed in such a manner as to admit of progressive development to meet the maximum needs of a deep waterway. Locks and all permanent structures should be constructed for maximum depths even though the intervening channels be excavated at the outset for the 21-ft. depth advocated by Mr. Wisner. That is a concession to the greater project which seems to be justified by American faith in America's future. Mr. Randolph.

Archibald A. Schenck, M. Am. Soc. C. E. (by letter).—This valuable paper opens up two important inquiries: Mr. Schenck.

(1) Are Lake vessels for commerce on rivers and canals more profitable ultimately than small barges and canal boats?

(2) Should our "seaports" be located at the sea or in the interior?

There is no doubt that the free ocean freights can be handled for less than ½ mill per ton-mile for long voyages. On the "half way free" Great Lakes, freight can be handled for less than 1 mill per ton-mile, where the voyage is the longest possible—Chicago or Duluth to Buffalo. This voyage may include travel through short stretches of canal connecting large open lakes. Owing to the lack of intermediate large basins (such as are the Lakes), in the proposed long canal and canalized river through New York State, no freight rate can be positively given. No actual test has been made for such long distances of narrow canal crowded with deep-draft vessels so thickly, without relieving basins. A comparison by highest speeds is hardly a safe financial operation. A railway train on one road can make 10 miles per hour on long stretches of track—on another road it will make 40 miles. Therefore, does the latter road carry freight for one-fourth the rate of the other? The consumption of time and money on most railways is not in transit, but while waiting to get into transit. On the canal, crowded with numerous vessels, the passing of opposing and overtaken vessels will reduce the speed to one-half, often to one-fourth, occasionally to one-tenth of the maximum speed. The vessel must run "on caution card" most of the time, even when having the right of canal; all this, apart from the mechanical difficulties in a

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* Chief Engineer, Sanitary District of Chicago.

Mr. Schenck cramped waterway, and with poor steering power, which are well-known causes of retarding. The premise of Mr. Mayer—tested speed over measured lengths—leaves out of sight all the difficulties of transit over which the railway man grows sad, even on a double-track railway, and which will exist largely on a canal. Such difficulties and delays on a long and narrow canal would lessen his 8-mile speed to a small fraction of it as average speed; will multiply by several times his 0.6 mill per ton-mile, and will cut into several small pieces his $1.50 per ton saving.

With these allowances, he is then in competition on river and canalized river with the immense tows of small boats, and on the ocean with the immense ocean carriers. His boat has neither great divisibility nor great mass.

The cheapness of these great tows of shallow boats is seldom noted by those who urge deep-water canals. On the Mississippi about 30 000 000 tons have been carried annually at a rate of 0.5 mill to 2.0 mills per ton-mile, with trifling investment in vessels. The tonnage reaching Hamburg by the Elbe is on water from 2 to 6 ft. in depth. On the Rhine, the Elbe and the Oder, the "strings," or tows, reach 10 000 tons each. On the Hudson they run from 10 000 to 15 000 tons, with draft of 6 ft. The towage rate is about $\frac{1}{10}$ cent per ton-mile. This low rate is not the only, or, perhaps, greatest, advantage of these tows. Their divisibility enables them to secure return cargoes, or cargoes of various sorts for many uses and many ports. Their light draft enables them to enter a vastly greater number of ports, ports for which the expense of construction and maintenance is trifling compared with deep-vessel ports; to secure an immensely greater variety and number of customers and shippers; to gather their freight nearer the producing point and deliver it nearer the consuming point, with little intermediate tribute paid to middlemen. These tows more nearly resemble the railway trains, in their divisibility and power of reaching close to consumer and producer, than any other form of water transportation that exists or can exist. It is doubtful whether the cheapening on canals and rivers in freight of moderately deep-draft Lake vessels would equal in cash value the gain those light-draft vessels have. At the ocean shipping port they can gather about and get closely "in touch" with large or small vessels, in deep or shallow docks, as no deep-draft Lake vessel can. They are the convenient, adjustable unit, perhaps never to be supplanted in inland narrow navigation for freights.

Again, the Lake vessel is also at a loss in competing against ocean carriers. It is dwarfed, stunted by its inland channel and ports and its effort, so to speak, to run on both sea and land. The tendency of ocean carriers to greater tonnage and draft can readily be noted by examining a few well-known trans-atlantic steamers.

Mr. Schenck.

TABLE No. 1.

Steamer.	Length, feet.	Beam, feet.	Draft loaded, feet.	Tons.
Umbria	502	57	28	8 128 Gross.
Teutonic	582	57	29	9 685 "
Majestic	582	57	29	9 861 "
City of Paris	580	63	27	10 500 "
City of New York	580	63	27	10 500 "
Kaiser Wilhelm	648	....	....	....
Oceanic	704	68	....	17 040 Gross.
New Liner, *Harland-Wolff*	750	....	....	12 000 Net.

The function of each class of vessel is essentially different. The proper style of inland vessel, small, penetrating everywhere; the ocean carrier, as large as the greatest ports will permit. The 24-ft. seaport entrance of former days, the 30-ft. entrance depth of to-day, are already outgrown; a 40-ft. entrance is now demanded. The increased tonnage is mostly clear profit, and the Lake vessel can never get that profit. It must go down before such ocean competition. It is neither one thing nor the other, neither truly inland nor truly oceanic. Our inland lakes, too large and dangerous for river vessels, too small and with ports too shallow for ocean vessels, are an inconvenient intermediate. A canal to connect two bodies of water having similar vessels is reasonable. A canal to connect two bodies of water much different, not adapted to the same class of vessel, is not desirable, or likely to be profitable. It is partially like trying to connect a narrow-gauge road and a broad-gauge road for running through trains. Lake vessels will not fit an ocean—ocean vessels proper cannot get upon the Lakes or use Lake ports. The effort to extend these Lakes seaward, as if they were deep-draft ocean waters seeking similar waters, is likely to be costly and unprofitable. Hence, "let the Government attempt it, it can afford to lose."

The pressure for this waterway appears to come from four directions:

(1) The great steel-producing plants, the Carnegies, Rockefellers, etc.: They can exterminate the middlemen, be producers and reach to the foreign consumer. Their gain comes, not so much in decreased transportation cost, as in annihilated middlemen. Only immensely wealthy concerns can thus act as producer, carrier and foreign merchant. The usual blocks of distance, into which commerce divides itself, must be made in all but such cases, and take place where bulk can most advantageously be broken—at the coast.

(2) From small shippers, to reach inland consumers: For these, the majority of the boats on canal and river should be small, receiving from the Lake boats as now, and delivering to them. The remedy of

Mr. Schenck. present cost lies in lessening transfer costs rather than in deepening waterways.

(3) The great mid-continental railways that reach from Pacific tide water to the Lakes: These are anxious to make seaports of their Lake terminals, and be independent of railways further east. Each wishes to unite Europe and Asia by a single line—its own.

(4) The numerous Lake cities, each eager to become a Greater New York:

All these efforts to transfer seaports to the heart of the continent are unnatural. Millions and hundreds of millions of dollars have been wasted, in recent years, in attempts to draw ocean commerce far inland. A few more hundreds of millions are now to be added, perhaps. The civil engineer, manager of transportation and capitalist, can find no larger or more important problem. It is worth the most painstaking study, with millions in it, or to be lost by it. It cannot be taken up as light reading or for temporary amusement. A correct, generally accepted decision as to whether our ocean ports should be far inland or far oceanward, would tend to save and make more millions than any other question the civil engineer encounters. This canal project is only one more struggle in the expensive contest of ports.

One of the causes of this contest has been that mere shipping ports and great marts of trade have been supposed to be one and the same thing. All that each town has aimed for has been to be a shipping port, a mere transfer table (with very little profit dropped in the transfer, it is found). All that railways have sought to reach has been a shipping point at which to dump their freight as near at hand and with as short a road as possible. The effort to ascertain the natural mart of trade and interchange, and to reach it has seldom been made.

The two alternates of location have been at the "head of navigation" and at the coast. Navigation is generally hydra-headed, and "the" head of navigation varies and dwindles in size and importance with draft of vessel until it becomes microscopic and unascertainable. An "immutable law" is claimed to put the great shipping port and mart of trade at this "head of navigation." The real test of commercial supremacy, such as the Lake ports are seeking by this canal, lies at the foot of inland navigation, always a distinct thing. This is the outermost point where inland vessels and great tows can safely go and transfer into the great ocean carriers. It is where the two can unite without sacrifice to either in respect to deep draft for ocean or light draft for small waterways.

At such a point the ocean vessel, the river vessel, the railway, can all get together. It is the only real radial point on the earth's surface. Land, ocean, coast, all productive areas, are naturally tributary and accessible to it. If the ocean carrier comes hundreds of miles inland, Mr. Schenck.

it passes rich areas, full of business. If it brings freight for this coast area, that freight must have a double needless journey after delivery inland. The coasting vessels must come far inland to exchange freights with the ocean carrier. The railways must carry back nearer to the coast what has already passed the coast inbound.

In support of the seaport far inland, and expensive projects for bringing vessels to it, existing ports are quoted. They are the main apparent argument. It is said that vessels must penetrate to the consumer, and the mart of trade be there. The consumers passed and ignored on the inland journey are not counted as of importance. A few figures in Table No. 2 will indicate what rich productive areas would be run through if a vessel could and did come far inland past the territory of each road named.

TABLE No. 2.

Road.	Through tonnage.	Local tonnage.
New York Central	2 023 133	14 598 064
Pennsylvania	2 189 804	35 809 588
Southern Pacific, Pacific System	738 914	4 949 142

Such are some of the rich tonnage-producing territories which the new Lake vessels would ignore and run past, in order to reach the inland port and get "nearer the producer and consumer." The vastly greater number of buyers, greater number of profitable whole-cargo lots, greater radial possibilities of distribution to all the country, are ignored by the vessel whose only aim is to go burrowing far into the land, in place of sending its load, promptly on reaching land, to every possible direction.

The actual ports cited as favoring the vessel's search inland, are numerous. None of them is really far inland, many wish they were less so. Some of the "inland ports," as contrasted with the ocean or coast ports, are the following:

"Inland ports"—Hamburg, Bremen, London, Glasgow, Gloucester, Montreal, Philadelphia, Baltimore and New Orleans.

Some of the coast ports are Liverpool, Southampton, Boston, New York and San Francisco.

These inland ports were located before railways reached readily to the coast. They attained importance when slow water transportation was the only form of transportation. They were in areas which had developed close to the rivers (then the only transportation routes) as towns now spring up along railways. The draft of vessels was small. Time was not an object in travel, in making sales, in turning over capital. In the present days time governs in all these, as essen-

Mr. Schenck. tial; speed in transactions multiplies capital. Quick fluctuations compel quick deliveries by ocean carriers. Protection is afforded to commercial cities at the coast. Fresh water does not have to be sought far inland.

Hamburg was founded in 808 A. D., became a free city, and secured valuable commercial privileges which more than compensated vessels for going a short distance inland. It is in a fine radial location of water transportation, having tributary to it 2 000 km. of waterways. It has expended immense sums for facilities, having 300 acres of basins, many miles of wharves, 30 000 sq. ft. of storage. Its facilities are worth $50 000 000 per annum to commerce. Railway transportation came too late to change its location.

Bremen is not a port, having only 8 ft. of water.

London was located under early conditions. Although it often in early days congratulated itself on being inland a short distance, because of protection from hostile fleets, it has regretted it for commercial reasons, and made every effort to overcome its disadvantages. Since the increase of railway facilities, its annual tonnage has become about 17 000 000, against 20 000 000 for Liverpool and much for Southampton.

Glasgow is in a great coal and iron producing country. It is not a commercial but a manufacturing city, and attained a population of 300 000 before railways came.

The American ports named as inland were also located and grew to large size, as a result of water facilities, before railways came. New York, a coast port, once much smaller than Philadelphia, is now many times larger. Boston's foreign commerce exceeds Philadelphia's many times. The inland port of Albany and the inland ocean waterway, the Hudson River, were deserted by ocean vessels through railway competition which placed the freight down at the ocean for the ocean carriers, and through competition of the great tows on the Hudson. No better practical illustration of how needless is an inland waterway for ocean vessels can be found than this same Hudson River, on which this inland attempt is desired to be renewed.

Philadelphia made every possible effort to draw ocean vessels generally to her wharves. The immense capital and tonnage of the Pennsylvania Railroad were backing the attempt. Great elevators were erected. The river was deepened and range-lighted by Government. The ocean business failed to come, except in years when coast ports and steamers of all drafts were overtaxed. Much of the elevator machinery went to the junk shop. President Roberts read the burial service as follows before the directors:

"Some years ago you established a steamship company, the American Steamship Company, fostered by your corporation, in which you took four-sevenths of the original stock, afterward increasing that from time to time until you had nearly $1 200 000 invested in the capital stock of that steamship company. Mr. Schenck.

"That $1 200 000 has been totally sunk. In addition to that, this company has faithfully paid the obligations, all these years, at the date of their maturity, so that they have paid in the neighborhood of $2 500 000, more as a contribution on the part of your corporation to endeavor to build up the commerce of this port; not an illiberal contribution, and one which has given the managers of your corporation some anxiety as to whether it was right or proper; but right or not, it is all gone."

Similar bad results are becoming observable at Montreal, New Orleans and Portland, Ore., while Boston, New York and San Francisco, well to seaward, are wearing no funeral colors, and plucky Galveston, seaward and even in the sea, is reviving, and shipping its greatest cargoes to-day. There may be another Philadelphia experience on a scale of hundreds of millions instead of millions. This time a rich nation, instead of a rich corporation, will be asked to take the risk and bear the loss.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS AND DISCUSSIONS.

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THE PRACTICAL COLUMN UNDER CENTRAL OR ECCENTRIC LOADS.

Discussion.*

By Joseph Mayer, M. Am. Soc. C. E.

Mr. Mayer. Joseph Mayer, M. Am. Soc. C. E. (by letter).—This paper contains a valuable collection of tests of columns, and is an interesting effort to derive, by means of mathematical reasoning, formulas giving the fiber stresses in actual columns.

The author appreciates the necessity of introducing empirical coefficients in his formulas, for the purpose of allowing for eccentricity of loading, initial curvature, etc., to make them agree with the tests. One of the purposes of the paper is to find formulas or curves for the ultimate strengths of columns. The curves obtained deviate very far from the ultimate strengths of short columns shown by the tests. The engineer cares most for the strength of columns of a length of less than 150 radii of gyration, and the curves of ultimate strength ought to be approximately correct for these columns. For all kinds of steel, wrought-iron and wooden columns it is possible to find straight lines which agree better with the actual ultimate strength shown by the tests of columns of less than 150 radii of gyration than the author's complicated curves. These straight lines are more convenient for use and more easily remembered.

The engineer desires to use dead loads per square inch equal to half of those producing stresses equal to the elastic limit. For very

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* Continued from August, 1900, *Proceedings*. See March, 1900, *Proceedings* for paper on this subject by J. M. Moncrieff, M. Am. Soc. C. E.

short steel or wrought-iron columns the elastic limit is about 0.6 of the ultimate strength. The proper dead load is, therefore, 0.3 of the ultimate strength, and the ultimate strength is about equal for tension and compression. For longer columns, the elastic limit and ultimate strength are nearly identical. A curve which starts with 0.3 of the ultimate strength for columns of no length and approaches half the ultimate strength of long columns answers the purposes of the engineer. Mr. Mayer.
A straight line of the equation $u = a - b\,\frac{l}{r}$, where $a = 0.3$ of the ultimate strength of the steel or wrought iron of which the column is made, $b = \frac{a}{250}$, will give the proper unit strain u for the dead load of columns of less than 150 radii of gyration, with as much accuracy as the uncertainty of the case allows. More complicated formulas would only be justified if they agreed more closely with the tests than do these simple formulas, which is not the case for columns of moderate length which are alone used in practice.

The formulas become, therefore, for iron $14\,000 - 56\,\frac{l}{r}$; for medium steel $18\,000 - 72\,\frac{l}{r}$.

The usual straight-line formulas for timber are as accurate as the author's formulas. While the writer, therefore, cannot agree with the author in his conclusions, he highly appreciates the services rendered by the latter in collecting the tests and presenting his views in such a lucid and simple manner.

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THE THEORY AND PRACTICE OF PRECISE SPIRIT LEVELING.

Discussion.*

By Messrs. RUDOLPH HERING, H. M. MARSHALL, ALEXANDER E. KASTL, H. M. WILSON, E. G. FISCHER and J. H. HAYFORD.

Mr. Hering. RUDOLPH HERING, M. Am. Soc. C. E.—It might be said, in connection with Mr. Wilson's discussion, that the European practice, which has very thoroughly covered this field of precise leveling, is inclined toward obtaining the greatest attainable precision and accuracy, but within practicable limits; which seems to correspond with Mr. Molitor's views. In important cases, it is certainly better to avoid errors in leveling as you go along, rather than to rely simply on the indications of your closure results, which may be due more or less to accident, from the possible fact that the closure error may be smaller than some intermediate errors. The speaker believes it to be proper, and in the line of progress, always to secure the greatest practicable precision warranted by the specific case.

Mr. Marshall. HORACE M. MARSHALL, M. Am. Soc. C. E. (by letter).—The treatment of the subject in this paper is exhaustive, but would lead one to believe that the work is very difficult; in fact, it is stated distinctly that "very few men have made a success of precise leveling." In the first place, that statement applies probably only to this country, where

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* This discussion (of the paper by David A. Molitor, M. Am. Soc. C. E., printed in *Proceedings* for September) is printed in *Proceedings* in order that the views expressed may be brought before all members of the Society for further discussion.

Communications on this subject received prior to December 28th, 1900, will be printed in a later number of *Proceedings*, and subsequently the whole discussion will be published in *Transactions*.

Mr. Marshall.

the method is of recent application, and in the next, only a few men in this country have tried it.

Under the United States Engineer Office at Vicksburg, Miss., no less than nine men have been engaged, from time to time, on precise level work, and there has been but one instance of failure. That was due to the man getting "rattled" by becoming imbued with the idea that the work was especially "scientific." It is exactly this feature which needs to be combated in order that the method may become more generally adopted on private and corporate work.

When any one talks about running levels to hundredths of a millimeter with a self-reading rod, they excite derision, though they may be happy in the knowledge that no one can prove the results incorrect. It smacks too much of theory and too little of experience. There is absolutely nothing in precise leveling save an accurate instrument (with a sensitive bubble) and a thorough programme for making the readings, to get good results. By thorough programme is meant one which will balance or detect errors; and it is not necessary to balance out the same errors twice. Equal sights balance instrumental constants; eccentricities cannot be balanced. To repeat the sight with instrument inverted and reversed is simply to balance out the constants twice, so far as the instrument is concerned, and to delay the progress.

The record given in Table No. 21 shows that the progress, where the double readings were presumably taken by the author, was about 25 miles per month. The last line run under the Vicksburg Engineer Office was at the rate of 59.3 miles per month in the field, for a distance of 222 miles. The best day's run was almost exactly 10 miles of single line, and the line checked within the limit

$$5 \text{ mm. } \sqrt{\text{distance in kilometers,}}$$

the distance being counted only in one direction. This limit does not very greatly exceed the 3 mm. $\sqrt{2 \text{ distance in kilometers}}$ mentioned in the paper. A recomputation of the notes in the office usually changes the final result less than 1 mm.

For practical purposes, the source of error matters little so long as the programme remains unchanged by later discoveries. Whether it be the settling of the instrument or the change due to alteration of the temperature cannot be detected by any peculiarity in the movement of the bubble, nor is there any good to come from defining refraction differently from the meaning accepted in physics.

The condition of the atmosphere being unstable, of course, change in refraction is continually going on, and, by the way, this change, which is most detrimental to good work, is usually most rapid near sunrise and sunset, the very time the author selects for best results.

With a stable condition of the atmosphere the absolute temperature makes no difference, except that cold weather is not conducive to comfort, and it is a fact that some of the best work done under the

Mr. Marshall. United States Engineer Office at Vicksburg, Miss., was done during the summer time. An attempt was made to run at night, but proved unsuccessful because of the difficulty of properly illuminating the rods and instruments. Almost any nightwork is distasteful to the men, and is seldom as rapid as day work.

The programme proposed by the author varies very little from accepted practice, and the reversal of the telescope and bubbles is hardly worth while. In fact, any increase in the time required to complete a set of observations permits an increase in error due to change in atmospheric conditions, and adds weakness, unless the gain in some other feature more than counterbalances. Of course, it is equivalent to repeating the observation, but it delays the work and is likely to trip the recorder. To move the instrument before the notes of observation have been checked is distinctly a bad feature.

The refinement of subdividing the rod is probably most generally detrimental, for it increases the blurring effect of any boiling of the air. Possibly these fine divisions on the rod forced the choice for best running to the time of day when the air is steady, even if refraction is changing most rapidly.

To prescribe a particular direction for running, according to the time of day, having reference to the light, pre-supposes a constant direction of the line, when in fact the line is seldom straight. The convention in regard to signs for difference of elevation by lines in opposite directions seems hardly well taken. If it is up in one direction, it is down in the other, and the signs should show actualities.

Table No. 21 purports to show the accuracy of the "Principal Precise Level Work in the United States," and gives results on 2 048 km. by the Coast Survey and 2 849 km. by various United States Engineer Offices, but it seems a little curious that it leaves out that office which has done more precise level work than any other and about seven-ninths as much as all other engineer offices combined.

The same thing has occurred before, when an assistant engineer published a list in the annual report of the Chief of Engineers of the United States Army. The Engineer Officer in Charge made the *amende honorable*, however, when his attention was called to it.

Perhaps the Vicksburg office, formerly under Major J. H. Willard, and now under Major Thomas L. Casey, does not do "principal" precise level work, but it is, nevertheless, the only Engineer District which is fully covered by a system where all the polygons are closed. There are seven polygons, the perimeters of which vary from 20 to 294 km., with errors of closure from 0.7 to 101.6 mm. Taking into account the closures on lines run by the United States Coast Survey, there are six other polygons with errors from 4.1 to 146.8 mm.

The size of the polygons, the actual error of closure and the error in the closure, in millimeters per kilometer, are shown in Table No. 26.

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TABLE No. 26.

Polygons. Nos.	Perimeters, in kilometers.	Closure error, in millimeters.	Error, in millimeters per kilometer.	Remarks.
1..........	20	+ 0.7	0.035	
2..........	32	— 1.5	0.047	
3..........	165	— 14.8	0.079	
4..........	259	— 27.7	0.108	
5..........	528	— 46.0	0.089	
6..........	629	+101.6	0.161	
7..........	694	+ 98.9	0.142	
8..........	69	+ 4.1	0.060	Closed on Coast Survey.
9..........	303	— 93.5	0.308	" " "
10..........	343	— 26.6	0.077	" " "
11..........	471	+146.8	0.311	" " "
12..........	536	+ 45.2	0.084	" " "
13..........	680	— 84.1	0.124	" " "

It will be noticed that the greatest actual error of closure per kilometer is less than the least probable error per kilometer in the work cited in Table No. 21.

Of the allowable error, or the limit of error permitted, a good deal might be said, but it is, after all, simply an approximate test of the accuracy of the work, and only serves as a warning to show that the conditions will not permit good results under the usual programme when it is exceeded. The proper form would be an equation of the second degree, having the distance in one term to the first power and in another term to the second power. Probably the present form was worked out empirically from practice where the use of the level has got beyond the experimental stage.

The probable value of two results is the mean, and the error probably does not exceed half the difference between the two results; that is, if the difference is about the usual size for that character of work. To compute the probable error by least squares from two observations is foolishness; and as the observations on different lines, and even on the same line, are not made under similar conditions, *i. e.*, they cannot be considered as repetitions of the same observation, the probable error by least squares cannot properly be used even for comparison.

As said, the paper goes to the full limit in the matter of precise levels, but it is to be hoped that members of the Society will understand that the work is easy in practice. Almost perfect lines of levels can be run nearly as cheaply as ordinary levels are now run, and, if the mistake of cutting down the limit too small be not made, the work can be done more rapidly. All lines of levels on permanent works would be better if run by the precise level; lines on all water courses should certainly be.

The American instrument-makers turn out a more finished instrument than foreign makers usually do, but the Kern level is of a good, substantial make, which has stood the test of time for wear and good work.

Mr. Kastl. ALEXANDER E. KASTL, M. Am. Soc. C. E. (by letter).—The writer, having been engaged on precise spirit leveling, under the Corps of Engineers, U. S. Army, both as recorder and observer, has read with much interest this valuable paper.

Referring to Table No. 21, page 888, the writer wishes to call attention to a line of precise levels, not given in the table, run in connection with the Red River Survey, in 1889, 1891 and 1892.* The line runs from Delta, La. (opposite Vicksburg, Miss.) on the Mississippi River, to Shreveport, La., on the Red River; thence along the Red, Atchafalaya and Mississippi rivers to Smithland, La., on the Mississippi River. The length of this line is 654 km., or 406 miles. In 1880 and 1881, the U. S. Coast and Geodetic Survey had run a line of precise levels along the Mississippi River from Greenville, Miss., to New Orleans, La., which includes the Mississippi River from Delta, La., to Smithland, La. The length of the Mississippi River line from Delta to Smithland is 248.4 km., or 154 miles. The Red River Survey levels started from the U. S. Coast and Geodetic Survey Bench-mark No. 215 at Delta, with its elevation of †34.084 m. above Cairo Datum, and closed on the U. S. Coast and Geodetic Survey Bench-mark No. XLV at Smithland, with an elevation of 21.005 m. above Caro Datum. The elevation of Bench-mark No. XLV, by the U. S. Coast and Geodetic Survey is †20.983 m.; that is, the error of closure of the entire polygon or loop, Smithland, Delta, Shreveport and back to Smithland, is 0.022 m., being 22 mm., or less than $\frac{7}{8}$ in. The total length of the polygon is 902.4 km., or 560 miles.

The writer does not know the probable error per kilometer

$$\left(= \pm \sqrt{\frac{\Sigma\, r^2}{\Sigma\, L}} \right)$$

for the entire line as on the Red River Survey it was not deemed of sufficient importance to take the time to make the computations. The writer ran the last stretch of the Red River precise levels from Grand Bend, La., on the Red River, to Smithland, La., on the Mississippi River, a distance of 126.2 km., or 79 miles. For his own information he computed the values of r and r^2 for his line of levels and found the probable error for the 126.2 km. to be ± 12.3 mm., or ± 1.1 mm. per kilometer. The writer's method of computing the probable error was the same as that given by the author on page 891.

In running the Red River precise levels care was taken to keep the instrument closely adjusted and to keep the back sights and fore sights equal. The instrument was shaded with an umbrella, and no work was done from about 11 A. M. to 2 P. M., unless the day was

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[*] Annual Report of the Chief of Engineers, U. S. Army, Report of Captain J. H. Willard, Corps of Engineers, for 1893, page 1944 *et seq.*

[†] Report of the Mississippi River Commission for 1884; or, Annual Report of the Chief of Engineers for 1885, pages 2676 and 2678.

Mr. Kastl. cloudy. The length of sights was usually not over 100 m., except at river crossings, where the method of reciprocal levelings was used. The rod readings were taken with the level bubble in the center, telescope normal and level direct. Each stretch of levels was run in duplicate in opposite directions by the same observer, and during the same forenoon or afternoon. The level and collimation errors, although small, were observed and recorded at least at the beginning and close of each day's work and sometimes of each half-day's work. The correction for inequality of the pivots and the value of one division of the level for a distance of 1 m. were determined at the beginning and close of the season's work. However, as the instrument was kept closely adjusted, and the back and fore sights kept equal, the corrections for the inequality of the pivots and the level and collimation errors were rarely used. Is is a good plan to keep a record of the adjustments. The allowable limit of error for each stretch was 5 mm. $\sqrt{\text{distance in kilometers}}$, the distance being the length of the stretch from one bench-mark to the next, and not the length of the loop leveled forward and back. The instruments used were precise levels and rods, manufactured by Kern of Aarau, Switzerland, and had been used on the U. S. Lake Survey and on the Mississippi River Survey.

It would be very interesting if the author would give comparisons between the lines of precise levels along the St. Clair and Detroit Rivers as run under the U. S. Lake Survey* in 1877, and as run under the U. S. Board of Engineers on Deep Waterways in 1898 and 1899. The U. S. Lake Survey precise levels were about the first of the kind which were run in the United States, and a comparison of results between the first and latest methods of doing this class of work would be worthy of record.

Mr. Wilson. HERBERT M. WILSON, M. Am. Soc. C. E. (by letter).—This exhaustive paper on precise spirit leveling covers thoroughly the theoretic conditions involved in the practice of this class of surveying. It is especially pleasing to the writer and should be to this Society, because it substantiates, theoretically, the principal conclusions brought out by the discussion of the paper entitled, "Spirit Leveling of the United States Geological Survey."† Had Mr. Molitor examined this paper, he would not have stated that he is unable to give examples of speed or cost. Many such are to be readily obtained from a study of the reports of the United States Engineers, the United States Coast and Geodetic Survey and the United States Geological Survey, and a few are published in the paper above referred to.

The writer is glad to see that in this paper the title "precise spirit leveling" is used, thus bringing out clearly the fact that it is spirit leveling by which the most precise work is done, and not that variety

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* Professional Papers, Corps of Engineers, U. S. Army, 1882, No. 24, p. 599 *et seq.*

† *Transactions*, Am. Soc. C. E., Vol. xxxix, p. 339.

Mr. Wilson. of leveling wherein numerous instrument constants and corrections for "errors" are applied, to the detriment of the results.

Mr. Molitor points out very clearly that "the most perfect is not necessarily the most complicated instrument. On the contrary, simplicity is a prime necessity in the usefulness of a level." Elsewhere, he repeats, in order to point out clearly that in his opinion the best results are to be obtained by the simplest methods of running and of instrument and by the avoidance of those methods, practiced in the past, which require the application of corrections and constants to the instrument and its results before the latter are available for use. Yet, these admirable conclusions have been hidden by him under a mass of theoretic discussion of errors and instrument constants and their correction, which are so voluminously stated as to befog the conclusions to be drawn In point of fact, scarcely any of the constant corrections are to be applied to the methods preferred by Mr. Molitor, and few of the errors are not shown by him to be eliminated by the methods of observation practiced.

Level.—The writer partially agrees with Mr. Molitor that the level made by Messrs. Buff and Berger for Professor Mendenhall is one of the best precise leveling instruments ever made. Yet he speaks slightingly of the quality of the level made by the same firm for the Geological Survey, when, in point of fact, the differences between the two are almost wholly in minor points of construction. They differ prominently in but one feature—the omission of the attached bubble from the Mendenhall instrument and the use of the striding level alone on that instrument. The writer is inclined to agree with Mr. Molitor and others that the striding level is theoretically, and possibly practically, slightly preferable to a well-made attached level. The writer will show, farther on, however, that it is doubtful if any better results in precise leveling have ever been obtained than those secured by the Buff and Berger level (Fig. 2, Plate XXXVI), and it is not proven yet that the slightly more complicated, improved Buff and Berger is superior. A comparison made from Table No. 1 shows that in most of the essentials these two levels are superior to the other instruments described. After a conference on the subject of a new level for the Geological Survey, the maker of these two instruments was inclined to agree with the writer that it was doubtful whether the changes made in the Mendenhall level had not affected some of its simplest and most admirable qualities as a purely precise spirit level. Mr. Molitor makes a slight mistake in stating that on the Geological Survey instrument 6- and 8-second bubbles are used. In point of fact, 4- and 8-second bubbles are used, though the latter only under unusual conditions; the 4-second bubble being that which is generally used. The new Coast Survey instrument should be of superior make because of its reputed great simplicity.

Rods.—A very shallow coating of paraffine is preferable to any Mr. Wilson. other treatment, as it will keep out dampness, etc., more effectually than painting, and yet does not affect a sufficient amount of the cross-section of the rod to have an appreciable influence on its expansion. On this point, however, there is much to be learned, and rods either treated as above, or oiled and kept freshly coated with shellac, or painted, as suggested by Mr. Molitor, are probably equally satisfactory.

The conclusions to be drawn from a series of careful experimental levels run and re-run last year by the Geological Survey between Elmira and Corning, New York, with both target and self-reading rods of most approved patterns, indicated that there was little difference in the quality of the results obtained by either. In the matter of speed and relative cost there was a decided advantage shown in favor of the target rod, and these are points which engineers thoroughly appreciate. Self-reading rods are slower than target rods, because on even moderate grades the length of the sights must be materially reduced, since only a relatively small portion of the rod can be seen between the extreme of the three wires. Moreover, since it is desirable in such work not to observe nearer the ground than 1½ to 2 ft., because of refraction, it is apparent that only a very short rod is available and the lengths of sights and rate of speed are correspondingly reduced. Finally, the use of self-reading rods retards the work because of the time required to read and record all these wires.

Turning Points and Bench-Marks.—The use of pins for turning points, in preference to plates, has, as stated by Mr. Molitor, received the approval of nearly all precise levelers. The writer, however, disapproves of the hole sunk in the foot of the turning pin into which a projection on the foot of the rod is placed, because of the danger of dirt getting into such a cavity and being carelessly left there, thus vitiating the results. He also disagrees with Mr. Molitor's recommendation for the concealment of bench-marks. A very wide experience with these, in every part of the United States, and in the setting of thousands during the past few years by levelers for the United States Geological Survey indicates that publicity is better, and this is in accordance with the best European practice. The threat of fine, etc., printed on the Geological Survey bench-marks has its effect in deterring many from disturbing them, though in point of fact, as stated by Mr. Molitor, the conviction of a transgressor would be a very difficult matter. However, bench-mark tablets of large size, attractively labeled and placed in prominent positions in public buildings or grounds are decidedly more immune from injury than those which are smaller and concealed—this, chiefly for the reason that people living in the vicinity are proud of and become interested in the public and official mark showing the height of their locality, and would interrupt any

Mr. Wilson. vandal who would attempt to injure the same. Moreover, its very publicity makes it difficult for any one to disturb it without detection.

Simplicity of Precise Leveling.—It is feared that the imposing array of mathematical formulas and the statements as to the very high grade of personal attainments necessary in precise levelers will deter civil engineers who have good spirit leveling to do from attempting work of this character. To counteract this effect the writer insists that precise spirit leveling is not at all a complicated operation. It differs little from ordinary spirit leveling except in the quality of instruments and rods used and in the precautions taken in their use. At little expense over that incurred in the more crude methods of spirit leveling ordinarily used on engineering work, leveling of the highest order is possible. Nor are scientific attainments of a very high order requisite in the leveler. Such qualifications as are to be found in well-educated instrumentmen of a few years' experience with transit or level will generally suffice. Although for the best results only the best instruments should for safety be used, almost equally good results are being obtained daily over distances of less than 100 miles, such as engineers will ordinarily have to operate in, with nearly any spirit leveling instrument of good make. It is not necessary to point out to engineers that the ultimate test of the quality of such work is not in theoretic discussions of minute errors. These are of value in pointing out the methods to be used and the cure for the errors; but the test of the result is in the error shown in starting from a given point, running 50, or 100, or 1 000 miles, and closing back on that point. No better results of this kind have ever been obtained than those procured under the direction of Mr. William H. Brown, Chief Engineer of the Pennsylvania Railroad, in running precise levels with a first-class Heller and Brightly instrument, or by the United States Geological Survey with an instrument of which Mr. Molitor says: "It is not really a precise level, but merely a good common level." Yet with these instruments the very best attainable closures have been invariably procured.

Unfortunately, the writer is not at this time able to quote the closure errors exactly because the leveling parties are still at work in the field, or because his present duties render them inaccessible; however, in a line 1 043 miles in length from the sea coast in North Carolina through Asheville and Knoxville to Atlanta, and back to the sea coast at Brunswick, Ga., including the errors of tidal observations at two points on the coast, the closure error was 1.057 ft., a result within permissible limits, when it is remembered that the total length of the duplicate line is twice 1 043, or 2 086, miles, and includes errors of two tide gauges. Equally good results have been had in closing a circuit of 780 miles, half of which consists of the United States Engineers' line from Albany to Oswego and water levels on Lakes Ontario and Erie to

Dunkirk, and the other half of Geological Survey levels from Dunkirk *via* Binghamton to Albany, the closure error being 0.645 ft. Mr. Wilson.

This year the Geological Survey "common levels" have closed, within 0.246 ft., a line run from the old United States Engineers' bench-mark at Utica north to Mr. Molitor's own line for the Deep Waterways Commission at Fort Covington. At Pittsburg the Geological Survey levels checked on a bench-mark of the Pennsylvania Railroad "common levels" and with a line brought by the Geological Survey from the Coast Survey bench-mark at Grafton, W. Va., to Pittsburg. The extreme range of closure was 0.368 ft. in a distance of 1606 miles. The elevation brought by the Pennsylvania Railroad direct from Sandy Hook is 738.491 ft. That brought by the Coast Survey from Sandy Hook to Grafton, and by the Geological Survey thence to Pittsburg, is 738.468 ft. The discrepancy between the elevation brought by the Geological Survey from Lake Erie, dependent on the old United States Engineers' levels from Albany, and the Pennsyl-

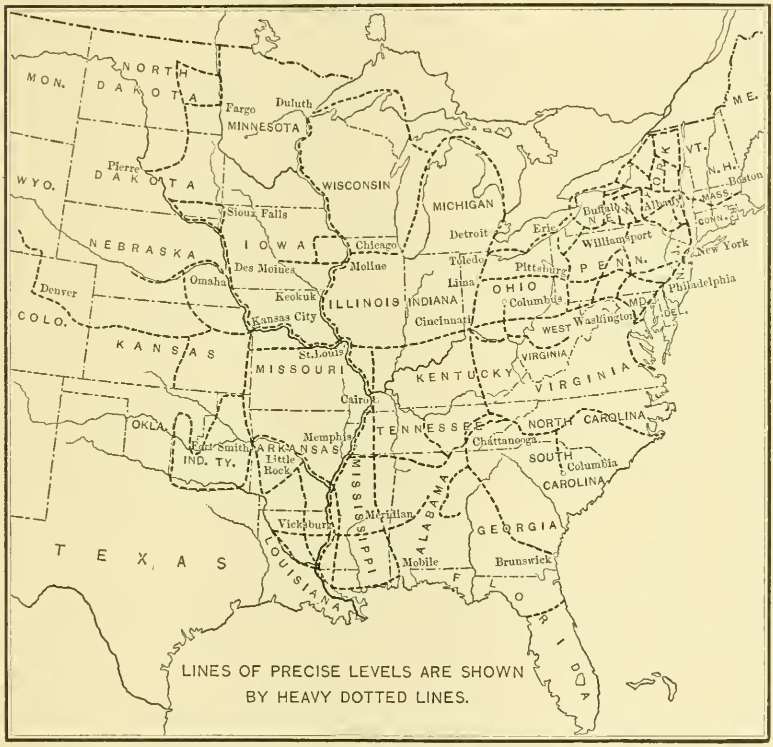

FIG. 18.

Mr. Wilson. vania Railroad, in 1 227 miles, was 0.215 ft., accepting the present height of Albany, or about 0.4 if Albany be corrected. At Harrisburg the closure error between the Pennsylvania Railroad, the Geological Survey and the Coast Survey was 0.079 ft. in 376 miles.

The line just closed by the Geological Survey on a Coast Survey bench-mark at Poughkeepsie, from a Geological Survey bench-mark at Binghamton, shows an error of 0.607 ft. This includes a circuit from Poughkeepsie by the Coast Survey to Albany, thence a mean of United States Engineers' and Geological Survey levels *via* Dunkirk to Binghamton. This closure goes to show that the revised Grist-mill bench-mark at Albany, characterized in the writer's paper of 1898,* is still in error by about half a foot, since the application of the closure error just obtained to results had through Harrisburg and through Pittsburg improves the closure at those and at other points made by lines brought from Albany and from other directions. Thus applying it, it makes a line to Harrisburg from Elmira and Albany close with the Pennsylvania Railroad 0.044 ft. low.

The writer desires to emphasize Mr. Molitor's statements about heat effects on the instrument, as he fully agrees with him that practically all the errors which cannot be eliminated in the instrument and in the running are those due to changes of temperature. Therefore, to do careful work of this kind, every effort must be made to minimize heat effects, and one of the essentials is that the instrument shall be at all times shaded from the rays of the sun. Even in ordinary leveling the bubble can be so much more quickly brought to center when the instrument is shaded, and the results will be so much more trustworthy, that the cost of an umbrellaman will practically be saved in a short time.

The members of this Society will be interested to know that, as a result of the writer's paper on leveling,* he has the personal statement of the Superintendent of the United States Coast Survey, Professor H. S. Pritchett, that the Coast Survey is indebted to that article and its discussion for its clear proof of the necessity of a revision in their methods of precise leveling. That Bureau discarded in 1899 the instruments and methods theretofore used, and is now using a new instrument made by it which is similar to but even simpler than the Kern and the Buff and Berger levels. The chief point brought out, as a result of the conference of experts which recommended the changes, was that the largest source of error was due to temperature and the expansion of metal in the instruments; and that, therefore, any attempt to introduce instrumental constants, as had been done in the past, was erroneous because of the uncertainty of the coefficient of expansion and its effects on the parts of the instrument. This alone is a striking argument for the use of the simplest instrument and the simplest

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* *Transactions*, Am. Soc. C. E., Vol. xxxix, p. 339.

Mr. Wilson.

methods without the application of corrections for so-called instrument constants.

The members of this Society will be interested to know that now nearly the entire eastern half of the United States is thoroughly gridironed by lines of precise levels. It is scarcely necessary to go more than 100 miles in any direction to get a bench-mark which is connected directly with sea level by precise levels. For the benefit of those who are interested in the use of such results there is published herewith an outline map, Fig. 18, showing the distribution of such level lines. In many places there are adjusted between them other lines of levels derived from numerous reliable sources. The completeness of the precise level net in New York and Pennsylvania attests the progress being made in the co-operative topographic surveys of those states. Descriptions and elevations of all precise bench-marks can be procured by addressing the United States Geological Survey or the United States Coast and Geodetic Survey Offices.

Mr. Fischer.

E. G. FISCHER,* Esq. (by letter).—The writer, being an instrument maker, was particularly impressed by those portions of this interesting paper which treat of the form and material of the various precise levels and level rods. Having had charge of the construction of the instrument described therein under "*d*," page 792, also of the design for a reconstruction of that instrument, and the design and construction of a new one which has been in use during the past season, the writer feels that he may add to the interest in the subject of precise leveling by a description of an instrument and rod designed and constructed since any of those described by the author. A few remarks are added in regard to the instrument selected by the author as "the most perfect precise level yet produced."

It should be said here that the difficulty between the engineer and the "peculiarly obstinate" instrument maker did not prevail in the planning of what may be called the Coast and Geodetic Survey 1900 Precise Level. The engineer designated the method and the principal features required to satisfy it, and the instrument maker made the design which was approved by the engineer.

The method of observation adopted in the Coast and Geodetic Survey obviates the use of a revolving telescope and a reversible stride level. As will be seen in Figs. 1 and 2, Plate XLIV, the advantages arising from this fact have been utilized by mounting the level directly upon the telescope. By making the support for the telescope cylindrical, it was not only given the strongest and lightest form, but it could be made to serve at the same time as a protection to the level. The whole thus offers perhaps a minimum of surface to wind pressure, and is less readily affected by temperature changes.

Considering the minuteness of the quantities producing what are

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* Chief of the Instrument Division, Coast and Geodetic Survey.

Mr. Fischer. called cumulative errors, so minute that a most sensitive level is required to indicate them, the aims in designing the new precise level were to select the material with a view to the smallness of its expansion coefficient, to protect the vital parts against sudden and unequal changes of temperature, to reduce to the smallest possible dimension the linear distance between level vial and line of collimation, to ensure stability by reducing the distance between the center of gravity and the plane of support, and to enable the observer to obtain the rod reading, as nearly as possible, simultaneously with the setting of the level.

The material selected was the same as that which had been used in the reconstruction of the older instruments of the Coast and Geodetic Survey in the spring of 1899. The nickel-steel alloys, brought out by Professor Guillaume of the International Bureau of Standard Weights and Measures, had attracted considerable attention by reason of their low expansion coefficients (down to 0.000001 per degree Centigrade). Inquiry established the fact that tubing and castings, almost indispensable in the construction of instruments, could not be obtained, because attempts to produce them had not been successful. The writer, therefore, secured the co-operation of a brass founder, and after a number of trials succeeded in obtaining an alloy with a coefficient of 0.000004, which could readily be cast into suitable shapes. It is composed of 66 parts of a soft grade of cast iron and 34 parts of grain nickel. This is a metal almost proof against corrosion, though not better, as far as strength is concerned, than cast iron. A peculiar property is the readiness with which it takes polish and the smoothness with which it wears against itself even under considerable pressure. The nickel-iron draw tubes of the three reconstructed instruments, though moving in bearings of the same metal, do not show the slightest wear or looseness, though they have been used in running 200, 300 and 600 miles of double lines of leveling, respectively. This alloy, having proven its worth by a considerable improvement in the results obtained during the season of 1899, was also used in the construction of the 1900 levels of the United States Coast and Geodetic Survey, Nos. 7 and 8. The telescopes were cast with objective head and draw-tube bearings complete, with the aid of cores, as were also the tubes surrounding the telescopes, while the draw tubes and level tubes were cast solid and bored out. The screws which pivot the telescope, adjust the position of the level vial and the disc carrying the spider threads, and the leveling screw, are made of nickel-steel with a co-efficient of 0.000001, obtained from the firm* producing Professor Guillaume's nickel-steel alloys. As will be seen from Fig. 20, the telescope tube is cut open to admit of the level tube being placed as near to its axis as the cone of rays formed by the apertures of the objective and reticule will per-

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* The Société Anonyme de Commentry-Fourchambault, 16 Place Vendome, Paris.

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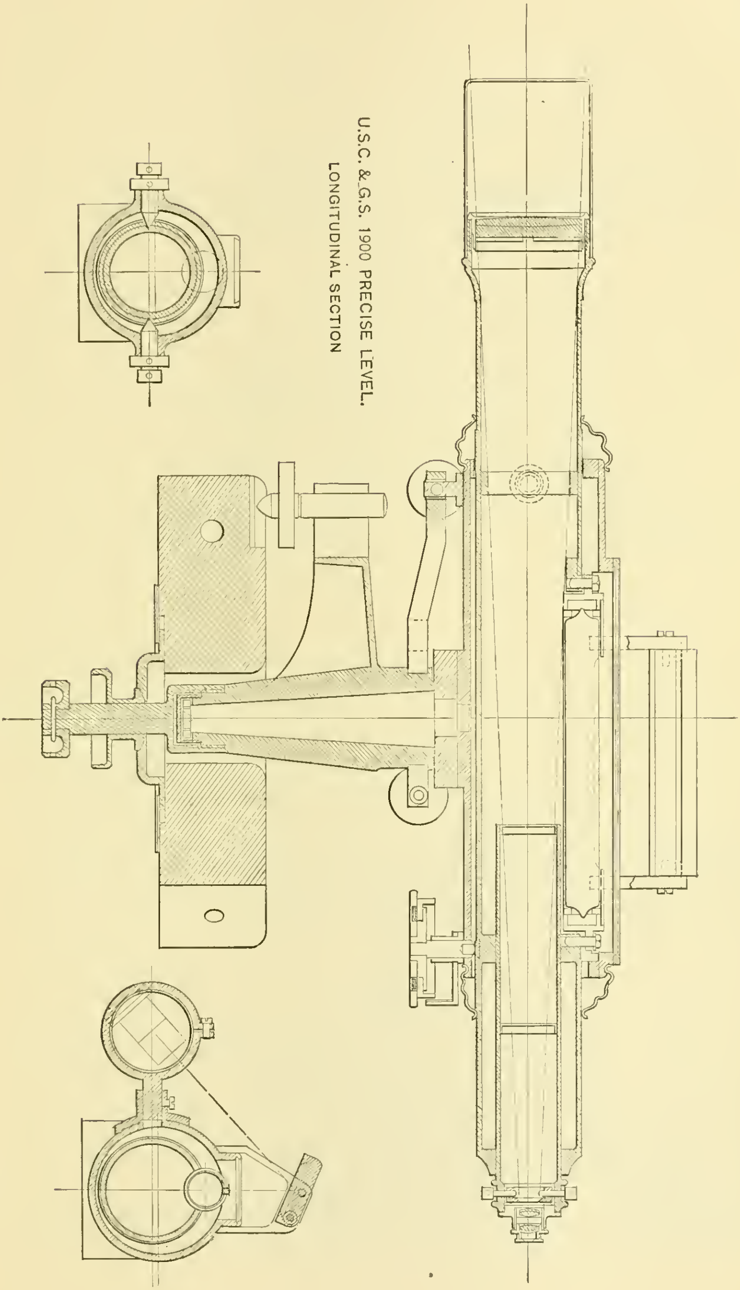

U.S.C. & G.S. 1900 PRECISE LEVEL.
LONGITUDINAL SECTION

FIG. 19.

FIG. 20.

FIG. 21.

Mr. Fischer. mit. The outer cylinder supports the telescope by means of the pivot screws shown in Fig. 19, the points of which enter at a place reinforced by a ring forming also a diaphragm; and the micrometer screw, the end of which carries a glass-hard steel tip upon which rests the telescope, which is provided with a small plate of glass-hard steel at the point of contact. A white celluloid head, graduated to 100 parts, and an index, serve to obtain quickly the horizon setting when placing the instrument. The pitch of the screw being about 39 threads per millimeter (100 per inch), gives a value of about 2.6 seconds per division.

The telescope has a vertical motion of about 2 mm. above and below the horizontal position. Just back of the micrometer screw is fastened to the outer tube a small eccentric with a lever handle, by means of which the telescope can be lifted off the screw and pressed against a spring above, to prevent jarring and disturbing the level adjustment while carrying the instrument from station to station. This device is not shown in the diagram, but can be seen on one of the photographs. The necessary openings between the telescope and the ends of the outer tube are closed by leather cones which effectually shut out dust and air currents, without in the slightest degree influencing the freedom of the telescope to assume the position determined by pivots and micrometer screw. The level tube holds the vial by six points of metallic contact, three at each end, 120° apart, the two lower ones being formed by the ends of screws piercing the tube, the upper one by a metal tip at the end of a flat spring fastened to the tube itself. The vial is confined longitudinally by cork rings, which, however, leave a clearance of about ½ mm. The level tube is fastened to the telescope at the end nearest to the ocular by means of a square-headed vertical adjusting screw of about 27 threads per centimeter, working against two very strong helical steel springs, and moved by a socket wrench with long lever arms, enabling the observer to make very delicate adjustments with ease. A turn or two of a small milled-head screw permits the glass cover over the oblong opening in the outer tube to be slipped back sufficiently for the admittance of the wrench. At the other end the tube is held by a clamping screw and two opposing screws for adjusting the level vial laterally.

Two slightly enlarged portions of the telescope tube, which are indicated in Fig. 20, but hidden under the leather cones in the photographic views, are turned to equal diameters, and as nearly as possible co-axial with the objective head and draw-tube bearings. By means of these collars, and suitable shop contrivances, the intersection of the vertical spider thread and middle horizontal thread is adjusted to fall in the geometric axis of the telescope, thus avoiding errors due to divergence between the line of sight and the line of motion of the draw tube. The level vial is also placed parallel to the line of sight

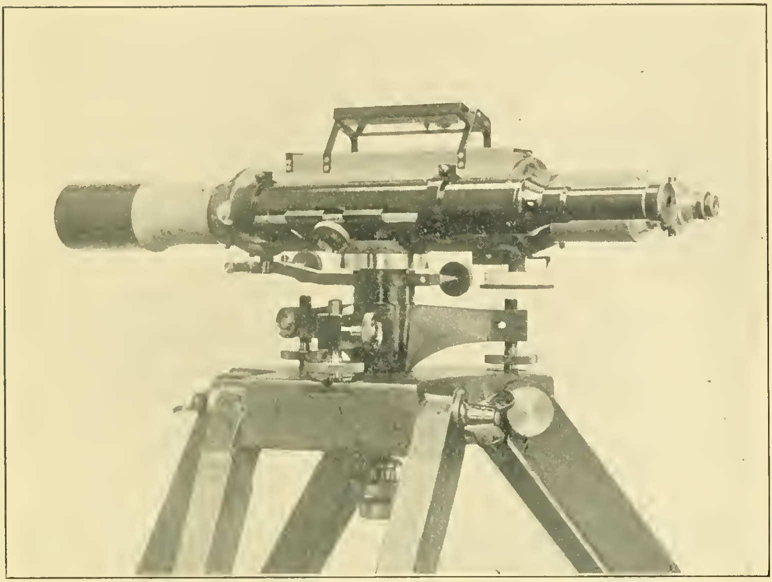

Fig. 1.—The Coast and Geodetic Survey Level of 1900.

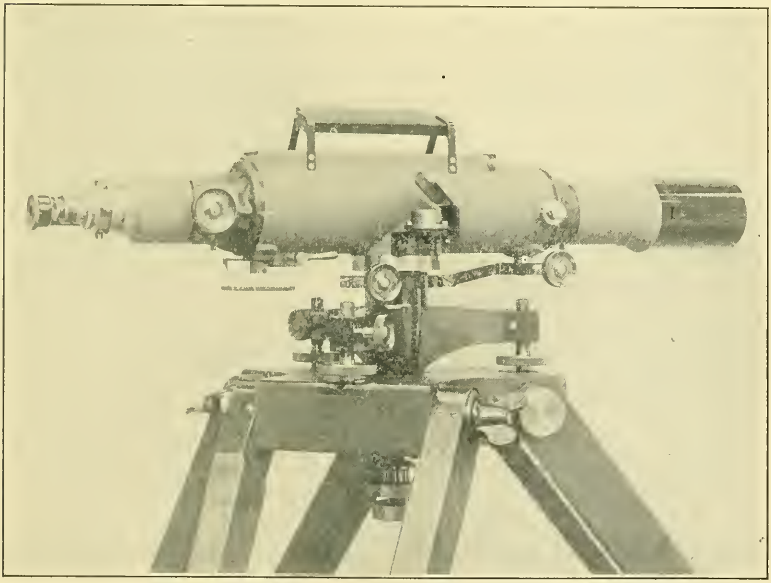

Fig. 2.—The Coast and Geodetic Survey Level of 1900.

Mr. Fischer.

in the shop, before the instrument is finally put together. The objective has a focal length of 41 cm. and a clear aperture of 4.2 cm. Two Steinheil eyepieces, of 9.5 mm. ($\frac{3}{8}$ in.) and 12.5 mm. ($\frac{1}{2}$ in.) equivalent focus, are provided, having magnifying powers of 43 and 32 diameters, respectively. The system of spider threads consists of one vertical and three horizontal lines. The upper and lower horizontal threads were placed to embrace a space of 30 cm. at a distance of 100 m., as requested by the engineer.

The outer tube and the telescope and level tube are covered with a substantial coating of cloth dust, to protect them against sudden changes of temperature.

The level-reading device (Figs. 21 and 22), is a modification of that made by Berthelemy (Fig. 2, Plate XXXV), and was first applied to the three Coast and Geodetic Survey instruments when remodeled in the early part of 1899 (Figs. 1 and 2, Plate XLV). The same device was adopted for the new instruments where it could be applied in a more compact form. The difference between the French device and its modification is readily apparent from the illustrations. The large and weighty mechanism has been reduced and placed near the base of the instrument, and, what is considered the most important change, the eye tube has been placed at binocular distance from the eyepiece of the telescope, enabling the observer to control both rod and level bubble as nearly simultaneously as his ability to change mental attention from one image to the other will permit. The distance between the axes of the telescope and level-reading tube can be adjusted to suit the individual observer. The images of the ends of the bubble and the scale divisions in their vicinity are reflected by the mirror above the opening of the outer tube into two prisms and are by them reflected, in a direction parallel to the telescope, into the observer's eye. The prisms have curved surfaces, and, together with a lens mounted between them and the eye end, reduce the distances between the ends of the bubble and the eye to the normal distance of distinct vision. The cap forming the eye end is arranged to hold such a lens as an individual observer may need to adapt the normal distance to an abnormal eye. The means of keeping the prisms adjusted symmetrically to the ends of the bubble are illustrated in Fig. 22. They are much simpler than those in the French instrument, in which racks and pinions are used.

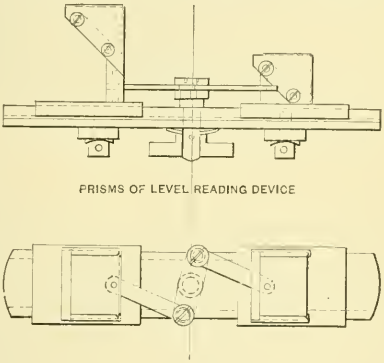

Fig. 22.

Mr. Fischer.

The level vials are graduated to 2-mm. spaces, and have values of somewhat less than 2 seconds per space. A small universal level with 45° reflector aids in quickly placing the instrument in operating position.

The centers are of the single-cone type, and are made of the hardest and toughest steel (Sanderson's Tool Steel No. 6), and fit closely into the tripod socket, which is made of a hard and fine-grained cast iron, furnished by the Brown and Sharpe Manufacturing Company. The distance from the line of collimation to the plane of support was reduced from 17.7 cm. in the old instrument to 10.9 cm. in the new, while the length of the center was increased from 7.3 to 10.0 cm. The radial distance of the foot screw is 9.0 cm.

The device for clamping the instrument to the tripod head for carrying from station to station is arranged so that the former cannot rest upon the latter unless the large clamp screw under the tripod head is screwed home, that is, the observer when mounting the instrument upon the tripod for the day's work, cannot forget to secure it so that the whole may be picked up and carried without accident. The weight of the instrument is 5.2 and that of the stand 7.2 kgr.

The writer feels seriously the weakness of the described instrument due to the loose texture of the alloy used for the telescope, level, draw and outer tubes, which would cause the instrument to suffer materially in an accident that would but slightly disarrange an instrument constructed of wrought metal; but the love and esteem it has won for itself from the user during the past season aids, to some extent at least, in shielding it against mishaps.

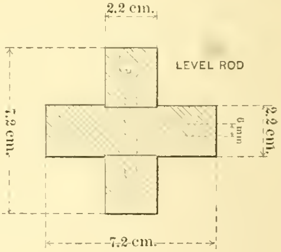

FIG. 23.

With the aid of the several photographs, Figs. 1, 2 and 3, Plate XLVI, and Fig. 23, there will be no difficulty in forming a clear conception of the level rod used during the seasons 1899 and 1900 in the Coast and Geodetic Survey. As will be seen from Fig. 23, the cross-section is symmetrical with reference to a central vertical line. A broad strip, carrying the graduation on one edge, is provided with two side ribs, forming with it a cross. The center of the foot, made of the hardest bell metal, is placed in the plane of the graduated face of the rod and is spherical with a radius of 2.6 cm. For control of the length of the rod, silver-faced plugs of 6 mm. diameter are inserted at the first decimeter above the foot, and at the 11, 21 and 31-dcm. marks above it, fine lines across them forming part of the graduation. Frequent measurements with the same steel tape during the season's work enable the observer to keep informed as to any changes

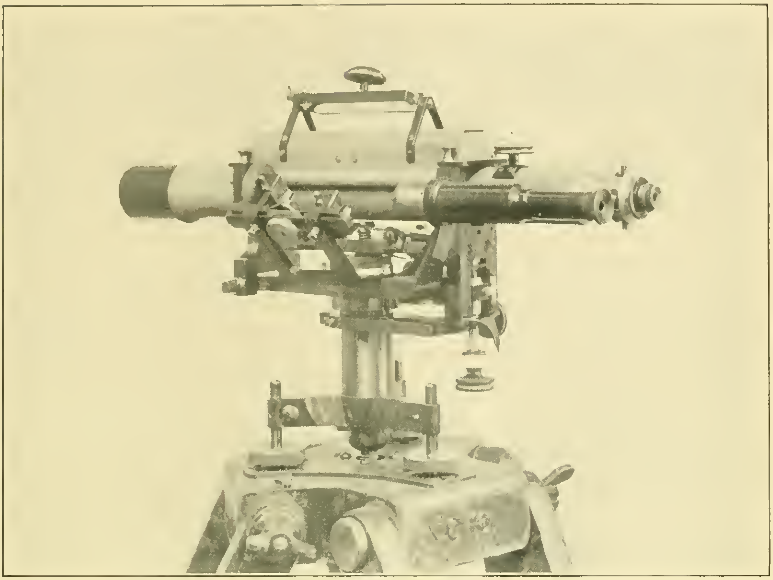

Fig. 1.—The Coast and Geodetic Survey Level of 1899.

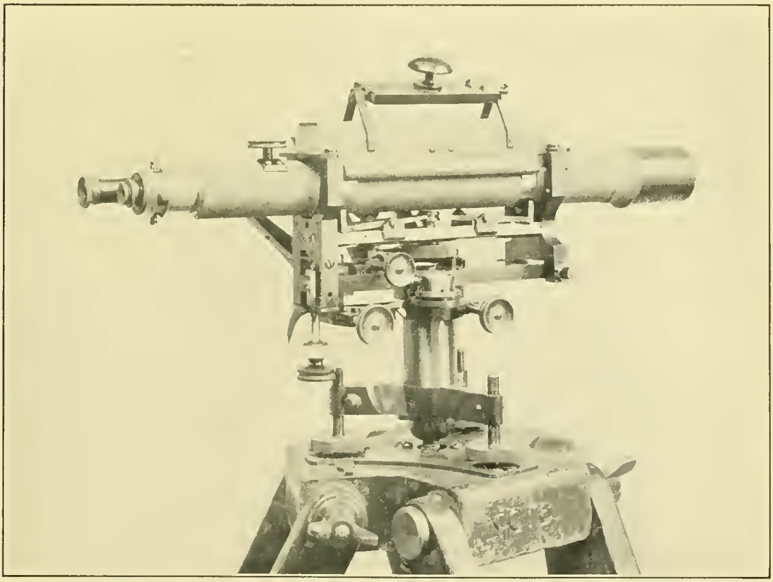

Fig. 2.—The Coast and Geodetic Survey Level of 1899.

Mr. Fischer.

taking place in the field and at what time they take place. The material from which these rods are made was treated with paraffine, but under considerably lower temperature than those mentioned by the author, so that the life of the wood, which is pine of a very light weight, is not appreciably impaired. The treatment was changed after the construction of the first pair of rods referred to in the paper, so that, although the paraffine was made to penetrate to the center of the strips of wood, all but about 19% was driven out again before allowing them to cool.

The author's statement that the coefficient of expansion of wood is increased by about 50%, according to determinations of the Coast and Geodetic Survey, must be based upon some mistake, since careful measurements gave a coefficient of 0.0000042, while that of untreated pine is usually given as 0.000004 (see page 834).

The handle, universal level and thermometer are shown in Fig. 3, Plate XLVI. The latter has a bent bulb which rests in the center of the cross-section and is surrounded by sawdust made of paraffined wood; the view shows the wooden protecting shield raised for reading the temperature. The weight of the rod, obtained from weighing two of them, is 4.7 kgr.

Fig. 24 is a plan and section of the foot plate. It is made of cast iron and the spherical cavity is turned to a radius of 3.6 cm., which is but little greater than that of the foot of the rod.

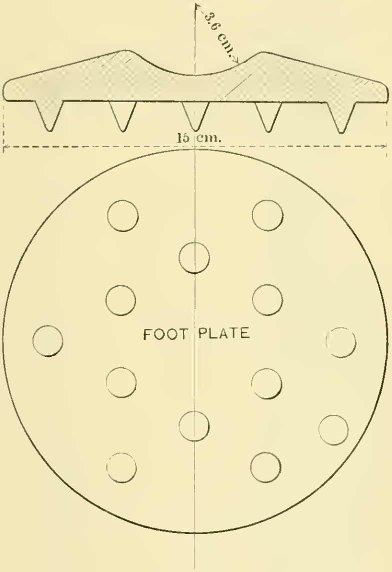

Fig. 24.

While, after all that may be said for or against the form and material of an instrument, the final test lies in the results obtained with it; and while the results obtained with the one selected by the author as the best may be better or worse than those secured with the one here described and others described in his paper, a matter which is left for the engineer and computer to decide, the writer cannot help but ask what particular features in the Buff and Berger level No. 2768 decided the author to select it from the rest of those he described. Its optical power is superior to that of any of the others; that of the Swiss level, though equal to it in diameters, is yet inferior by reason of its shorter focal length. The telescope is mounted nearer to the top of

Mr. Fischer. the vertical axis than in any of the other instruments, and the distance between level and line of collimation is apparently smaller than in any of the others except the Swiss level. These are points in its favor. But, on the other hand, would it not be a better instrument if it were not for the tall mirror and its supports, mounted where the wind must be most effective and forbid its use when another would be comparatively steady? Should not the level vial be protected from currents of air? The writer has observed, in an instrument mounted on a heavy stone pier, fluctuations of the level amounting to 1 to 2 divisions, in precise coincidence with puffs of wind too gentle to have caused the movements of the bubble by any other than temperature effects. Such air currents or puffs of wind would very likely attack also the upper half of the portion of the telescope shielded below by the cradle, and cause temporary warping of the line of collimation in a vertical direction which would not be controlled by the level.

The mounting of the micrometer screw at the end of a long horn extending out from the cradle support, to make contact with a similar one attached to the cradle, seems a large price to pay for the unimportant advantage of having the cradle swiveled in the center of the instrument. It admits of disturbances due to temperature effects and adds considerably to the already large area of surface exposed to wind pressure. The use of brass for the telescope and other parts of the instrument, with its high temperature coefficient of 0.000018, and especially the use of steel collars on a brass telescope tube, seems to the writer contrary to good principles in designing an apparatus for such delicate uses as those of a precise level. In the case of astronomical transits, meridian circles and other instruments of the highest order, where the control of the pivot axes by a striding level is of the greatest importance, it has been held for many years that, in order to preserve the true figure and equality of the cylinders forming the pivots, they should be supported in material which will itself yield and wear rather than cause their deformation. This was not regarded in the design of the author's favorite level, in which the steel collars of the telescope rest upon agate points, which must certainly indent them after but little use. Why not have had the collars rest across the whole width of bearings made of softer material than hardened steel? The author's statement that the four contact points of the cradle wyes should not lie in the same circles as those of the striding level would not be necessary if grooves were not worn in the collars. In the writer's opinion, ideal conditions can be reached more nearly by providing line contacts with wyes of some material wearing more quickly than that of the collars; in a very short time, really before the instrument goes to the field, these lines are worn into narrow cylindrical surfaces; if the wyes of the stride level are fitted in the same manner its readings can be relied upon for indicating the direction of the line

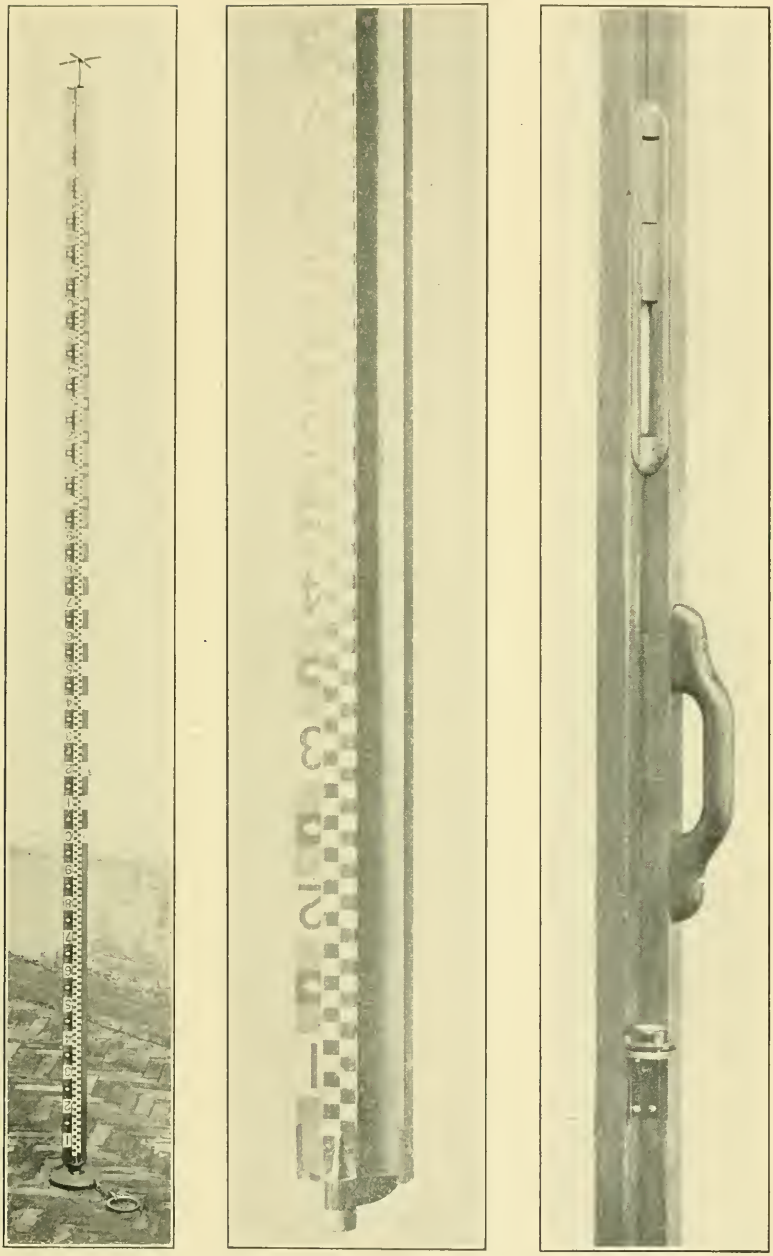

Fig. 1. Fig. 2. Fig. 3.

The Coast and Geodetic Survey Level Rod.

Mr. Fischer.

of sight and inequality of collars, provided, of course, that longitudinal motion is prevented. The writer cannot admit that mounting the level vial in its support by a strip of blotting paper or cork will secure the extreme stability in the make-up of a precise level. For the past twelve years all level vials, except the very smallest, of the instruments belonging to and made for the Coast and Geodetic Survey, have been mounted in the manner above described, that is, in metallic supports, free to follow temperature changes and free from effects due to swelling or shrinking of cork, paper, wood, etc.

Mr. Hayford.

JOHN F. HAYFORD, ASSOC. M. AM. SOC. C. E. (by letter).—The author's treatment of the subject of precise leveling has been read with interest, because it is evidently a serious attempt to solve a problem to which the writer has devoted much time during the last two years. The writer finds that he must dissent from several of the main points reached in the paper, as well as from many of the minor points. In expressing that dissent fully there is no intention of reflecting on the author's intellectual honesty, his ability, or his sincerity of purpose. The writer must express here his confidence in the high degree of accuracy attained in the two precise level lines run by the author. In the expressions of dissent in this discussion an attempt has been made to avoid making merely a statement of difference of opinion, thus leaving the reader to decide between opposing opinions without an adequate basis for his decision, and to state as fully as is possible in a discussion of readable length the points wherein the writer believes that the author's conclusions rest upon an insufficient basis, or wherein the foundation for an opposing opinion is more substantial.

The paper is very largely an advocacy of a certain instrument and a certain method of observation, together with a statement of the reasons for believing in such an instrument and method. It happens that another instrument and another method embody the views of the writer. It has, therefore, seemed that the best form for this discussion is to first describe the writer's favorite instrument and method, and to call especial attention to the most important points in which they differ from those of the author; to set forth in brief the considerations which led to the adoption of this particular instrument and method for use in the Coast and Geodetic Survey; then to call attention specifically to certain points in the paper; and to close, as the author has done, with a statement of the speed and cost of leveling.

Coast and Geodetic Survey Level of 1900.—As this instrument, together with the rods used with it, has already been fully described by Mr. E. G. Fischer, the designer of the instrument, it will suffice here to call attention anew to three main points.

1st. The instrument is irreversible, and as simple as possible. It will be seen later that this principle is coupled with the simplest possible programme of observation.

Mr. Hayford. 2d. Great care has been taken to prevent errors due to changes in the relative temperature of the different parts of the instrument.

3d. A device for reading the bubble has been supplied which enables the observer to stand erect at all times and see the bubble and the rod alternately and in quick succession, without moving the eyeballs, and without even refocusing the eye, the only change required being in fact a mere shifting of the attention from one eye to the other.

This instrument, put into use in 1900 in the Coast and Geodetic Survey, is radically different from the instrument used in the same organization previous to 1899, Fig. 1, Plate XXXVI. The 1900 instrument was preceded in 1899 by an intermediate type, illustrated on Plate XLIV. The 1899 type was produced by modifying the instrument, Fig. 1, Plate XXXVI, by redesigning the striding level in such a way as to bring the level vial and the line of collimation of the telescope much nearer together; by constructing the telescope barrel, including the collars and the principal metallic parts of the striding level of a nickel-iron alloy, having a low coefficient of expansion, about the same as that of pine; and by providing a device for reading the bubble similar to that described fully by Mr. Fischer in connection with the 1900 level.

Though it was possible to reverse the telescope of the 1899 level about its axis of figure, and to reverse the striding level, such reversals were not actually made during the course of the regular leveling observations, but only when determining instrumental constants. Hence, when the non-reversing method of observation had, during the working season of 1899, been found thoroughly satisfactory in every respect, it was but a logical step, in designing the new instrument, to make it irreversible, and, in doing so, to insure greater stability in the relative positions of its parts and to make its manipulation easier and quicker.

Aside from the advantages which may be claimed for the 1900 Coast and Geodetic Survey instrument over the Mendenhall instrument, which is the author's favorite—and also over the Kern instruments, which have been used extensively under the U. S. Corps of Engineers—which have already been mentioned and which imply an instrument maker's or office point of view, the following points will be especially appreciated by the observer in the field. The quotation is from an observer* who has probably run more miles of precise leveling than any other man in the United States, and whose work has been subjected to very severe tests by being involved in many circuits and has been uniformly found to be of the highest degree of accuracy. This observer used a Kern level until 1899.

"The 1900 instrument is a great success. In using it there need be no fear of the effects of dirt or dust, the Y's having been eliminated;

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* Mr. O. W. Ferguson, formerly engaged on various level lines under the Corps of Engineers, and now an Assistant in the Coast and Geodetic Survey.

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no fear that the level does not 'set right,' as there is with other instruments; no fear that the wind will tilt the striding level a little between back sights and fore sights and so change the inclination; no fear that the collars may have needed wiping; and no fear that an ill-directed motion of the hand has disturbed the relation between the level vial and telescope, or the verticality of the wires. This new instrument is about 15% quicker to manipulate than the Kern level or other instruments of that type. It is leveled up and made ready to observe quicker than the other instruments, and after observing it requires very little time to put the instrument in condition to be carried forward to the next station. The prisms, reflecting the ends of the bubble through the false telescope, are a great comfort to the observer. This device is superior to the inclined plane mirror often used for that purpose, for it concentrates the vision on the ends of the bubble and shuts out distracting patches of light and images of trees and other objects which sometimes appeared so prominent in the inclined plane mirror that it was hard to read the bubble."

Present Method of Observation, Coast and Geodetic Survey.—The method of observation used in the Coast and Geodetic Survey in 1899 is indicated in the following general directions which were issued to the observers in the field:

"1. Except when specific instructions are given to proceed otherwise, all lines are to be leveled independently in both the forward and the backward direction.

"2. It is desirable that the backward measurement on each section should be made under different atmospheric conditions from those which occurred on the forward measurement. It is especially desirable to make the backward measurement in the afternoon if the forward measurement was made in the forenoon, and *vice versa*. The observer is to secure as much difference of conditions between the forward and backward measurements as is possible without materially delaying the work for that purpose.

"3. On all sections upon which the forward and backward measures differ by more than 4.0 mm. $\sqrt{K}$ (in which K is the distance leveled between adjacent bench-marks, in kilometers), both the forward and backward measures are to be repeated until two such measures fall within the limit.

"4. The programme of observation at each station is to be as follows:

"Set up and level the instrument. Read the three lines of the diaphragm as seen projected against the front (or rear) rod, each reading being taken to the nearest millimeter (estimated) and the bubble being held continuously in the middle of the tube (*i. e.*, both ends reading the same). As soon as possible thereafter read the three lines of the diaphragm as seen projected against the rear (or front) rod, estimating to millimeters as before, and holding the bubble continuously in the middle of the tube. During all observations the telescope is to be erect and the striding level with a particular leg toward the objective—that is, there are to be no reversals of the telescope or striding level.

"5. At each rod station the rod thermometer is to be read and the temperature recorded.

"6. At stations of odd numbers the back sight is to be taken before the fore sight, and at even stations the fore sight is to be taken before the back sight.

Mr. Hayford. "7. The maximum difference in length between a fore sight and the corresponding back sight is to be 10 m. The actual difference is to be made as small on each pair of sights as is feasible by the use of good judgment without any expenditure of time for this particular purpose.

"8. The recorder shall keep a record of the rod intervals subtended by the extreme lines of the diaphragm on each back sight, together with their continuous sum between bench-marks. A similar record shall be kept for the fore sights. The two continuous sums shall be kept as nearly equal as is feasible without the expenditure of extra time for that purpose, by setting the instrument beyond (or short of) the middle point between the back and front rods. The two continuous sums shall not be allowed to differ by more than a quantity corresponding to a distance of 20 m.

"9. The inequality of collars shall be determined at the beginning and end of each season of work.

"The collimation error shall be determined once for each day of work, by a set of three readings in the direct position and two in the reverse position of the telescope.

"The error of adjustment of the striding level shall be determined at least twice on each day of work by a set of three readings in the ordinary position and two in the reverse position.

"10. Notes for future use in studying leveling errors shall be inserted in the record, indicating the time of beginning and ending of the work of each half day; indicating the weather conditions, especially as to cloudiness and wind; indicating whether each portion of the line is run toward or away from the sun; and such other notes as promise to be of value in studying errors.

"11. The instrument shall be shaded from the direct rays of the sun, both during the observations and the movement from station to station.

"12. The maximum length of sight shall be 150 m., and the maximum is to be attained only under the most favorable circumstances."

When instruments of the 1900 design were issued to two of the parties during the past season it was necessary to make the following changes in these general directions on account of the fact that the new instruments are not reversible:

"The last sentence of Section 4 of the general directions for precise leveling is now unnecessary.

"In place of Section 9 substitute 'Once during each day of observation the error of the level should be determined in the regular course of the leveling, and recorded in a separate opening of the record book as follows: The ordinary observations at an instrument station being completed, transcribe the last fore sight reading as part of the error determination, call up the back rod and have it placed about 10 m. back of the instrument, read the rod, move the instrument to a position about 10 m. behind the front rod, read the front rod and then the back rod. The rod readings must be taken with the bubble in the middle of its tube. The required constant C to be determined, namely, the ratio of the required correction to any rod reading to the corresponding subtended interval, is

$$C = \frac{(\text{sum of near rod readings}) - (\text{sum of distant rod readings})}{(\text{sum of distant rod intervals}) - (\text{sum of near rod intervals})}$$

The level should not be adjusted if C is less than 0.005. If a new ad-

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justment of the level is made, *C* should at once be re-determined. It is desirable to have the determinations of level error made under the ordinary conditions as to length of sight, character of ground, elevation of line of sight above the ground, etc.' "

It is important to note, although nothing in the foregoing directions bears upon that point, that the usual practice in the Coast and Geodetic Survey of continuing the observations throughout the day was not changed. The only concession made to the idea that observations should be taken only during the early morning hours or late evening hours was, that the period of rest at noon was sometimes made unusually long.

In order to obtain the actual lengths of the rods while in use in the field, the practice has been to have the rods measured accurately at the Office of Standard Weights and Measures, at the beginning and end of the field season, and to supplement these measures by tape measures made in the field once or twice a month during the field season.

The following examples of the record and computation will serve to explain the method still further:

TABLE No. 27.—Spirit Leveling.

Date, August 29th, 1900. Sun, C. Forward. From B. M. 68 to B. M. *G*. Wind, S. T.

No. of station.	Thread reading back sight.	Mean.	Thread interval.	Sum of intervals.	Rod and temp.	Thread reading fore sight.	Mean.	Thread interval.	Sum of intervals.
Time, 2.00 P. M.									
43..............	0 674	....	99	......	*V*	2 683	....	99	....
	0 773	0773.0	99	......	38	2 782	2782.3	100	....
	0 872	....	198	......	....	2 882	....	199	....
	0 925	....	106	......	....	2 415	....	103	....
44..............	1 031	1030.3	104	......	*W*	2 518	2518.0	103	....
	1 135	....	210	408	35	2 621	....	206	405
	0 484	....	98	......	....	2 510	....	96	....
45..............	0 582	0582.3	99	......	*V*	2 606	2606.0	96	....
	0 681	....	197	605	35	2 702	....	192	597
	0 398	....	97	......	....	2 859	....	96	....
46..............	0 495	0495.0	97	......	*W*	2 955	2954.7	95	....
	0 592	....	194	799	34	3 050	....	191	788
	1 027	....	26	......	....	1 006	....	29	....
47..............	1 053	1053.3	27	......	*V*	1 035	1034.7	28	....
	1 080	....	53	852	34	1 063	....	57	845
		3933.9	....	......	....	....	11895.7	....	
							—7961.8	....	
								2.25 P.M.	

The explanation of the symbols used after the words "Sun" and "Wind" is shown on the bottom of the computation form, Table No. 28. The unit in the record is the millimeter. The instrument stations (not turning points) are numbered consecutively throughout the day.

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TABLE

Left-hand page.

COMPUTATION OF

Line: Somerset, Ky., to Knoxville, Tenn.

B. M's.	Forward or backward.	No. of stations.	Sum of rod intervals.	Distance meters.	Rod intervals ΣB-ΣF	Mean Rod Readings.		Approximate difference of elevation.	Mean temperature of rods.
						Σ B Meters.	Σ F Meters.		
			mm.		mm.				
65-66	F.	9	3 669	1.279	+ 5	10.6532	19.0087	— 8.3555	37
	B.	7	3 675		+ 9	15.1650	6.8087	+ 8.3563	26
66-67	F.	8	3 738	1.302	+12	17.6667	10.4370	+ 7.2297	32
	B.	7	3 739		—23	7.8223	15.0537	— 7.2314	23
67-68	F.	13	4 198	1.464	+ 4	15.5276	31.8222	—16.2946	33
	B.	8	4 206		—24	21.5524	5.2587	+16.2937	28
68-*G*	F.	5	1 697	.590	+ 7	3.9339	11.8957	— 7.9618	35
	B.	6	1 691		— 5	12.5587	4.5979	+ 7.9608	31
G-69	F.	11	5 126	1.785	— 2	28.4990	5.8171	+22.6819	30
	B.	11	5 120		+14	6.3550	29.0368	—22.6818	27
69-70	F.	12	4 589	1.602	—23	17.7855	22.7719	— 4.9864	22
	B.	9	4 607		— 9	17.5312	12.5410	+ 4.9902	22
70-71	F.	10	5 000	1.740	+ 6	6.9331	27.1772	—20.2441	25
	B.	10	4 987		— 5	26.9183	6.6720	+20.2463	24
71-72	F.	10	4 076	1.420	+ 2	10.5955	26.0830	—15.4875	33
	B.	8	4 073		+ 3	21.0375	5.5510	+15.4865	26

Abbreviations: S.=sunshine; C.=cloudy; S. & C.=alternate sunshine and clouds, or alternate sunshine and shade.

Abbreviations, strength of wind: S.=strong; M.=moderate; C.=calm.

A rod once placed at a point stays there, both for the fore sight and back sight, the rodman thus being front and rear rodman alternately. To carry out the requirement of the general directions that at stations of odd numbers the back sight is to be taken before the fore sight, and at even stations the fore sight is to be taken first, it is only necessary to remember that this is equivalent to the statement that one particular rodman must always show his rod first after each placing of the instrument. The position of the rod is indicated in the record on the fore sight only. The temperature is read by the rear rodman just before he moves forward and is called out to the recorder when the rodman passes.

The columns headed "Thread interval" show the intervals between the lower and middle threads as seen projected on the rod, and the middle and the upper, and finally the total interval. The columns headed "Sum of Intervals" show the continuous sum of the total intervals, and, as these values are proportional to the sums of the back-sight distances and fore-sight distances, respectively, they enable the observer to keep these two sums nearly equal at all times.

Such portions of the computation as are shown in the tables as forming a part of the record, are kept up by the recorder as the work progresses. The instrument is not moved forward from any station

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No. 28.

PRECISE LEVELS. *Right-hand page.*

Observer, W. H. B. Year, 1900.

CORRECTIONS.				DIFFERENCE OF ELEVATION.		Divergence B-F.	Toward or from sun.	Sunshine or cloudy.	Wind.	Date and hour.
Curvature and refraction.	Level.	Length of rod.	Temperature of rod.	Each line meters.	Mean meters.					
mm.	mm.	mm.	mm.			mm.				
......	......	−2.3	−1.2	− 8.3590	− 8.3593	−0.6	L.	S.	C.	8/28- 9.15
+0.1	+0.1	+2.3	+0.8	+ 8.3596	....	......	......	C.	C.	8/29- 9.00
......	+0.1	+2.0	+0.9	+ 7.2327	+ 7.2334	+1.4	......	C.	C.	8/29-11.05
+0.1	−0.2	−2.0	−0.6	− 7.2341	....	......	......	C.	C.	8/29- 7.45
......	......	−4.6	−2.1	−16.3013	−16.3008	+0.9	T.	S. & C.	C.	8/29- 1.30
+0.1	+0.1	+4.6	+1.9	+16.3004	....	......	......	C.	C.	8/28- 5.00
......	+0.1	−2.2	−1.1	− 7.9650	− 7.9645	+1.0	......	C.	S.	8/29- 2.15
......	......	+2.2	+1.0	+ 7.9640	....	......	......	C.	C.	8/31- 9.00
......	......	+6.4	+2.6	+22.6909	+22.6908	−0.3	R.	S. & C.	M. S.	8/29- 3.15
......	......	−6.4	−2.4	−22.6906	....	......	......	C.	F. M.	8/31- 8.30
+0.1	−0.1	−1.4	−0.4	− 4.9882	− 4.9901	−3.8	......	C.	C.	8/30- 7.15
......	......	+1.4	+0.4	+ 4.9920	....	......	.....	C.	C.	8/30- 4.30
......	......	−5.7	−2.0	−20.2518	−20.2529	−2.2	......	C.	C.	8/30- 8.15
+0.1	......	+5.7	+1.9	+20.2540	....	......	......	C.	C.	8/30- 3.30
......	......	−4.3	−1.9	−15.4937	−15.4930	+1.3	L.	S.	C.	8/30- 9.15
......	......	+4.3	+1.6	+15.4924	....	......	......	C.	C.	8/30- 2.40

Abbreviations, direction of progress relatively to sun. $\left.\begin{matrix}\mathrm{T}\\ \mathrm{F}\end{matrix}\right\}$ = within 45° of directly $\left\{\begin{matrix}\text{toward}\\ \text{from}\end{matrix}\right\}$ sun. $\left.\begin{matrix}\mathrm{T_R}\\ \mathrm{F_R}\end{matrix}\right\} = \left\{\begin{matrix}\text{toward}\\ \text{from}\end{matrix}\right\}$ sun, but at an angle of more than 45° with sun to right. $\left.\begin{matrix}\mathrm{T_L}\\ \mathrm{F_L}\end{matrix}\right\}$ = ditto with sun to left. $\left.\begin{matrix}\mathrm{R}\\ \mathrm{L}\end{matrix}\right\}$ = sun to $\left\{\begin{matrix}\text{right}\\ \text{left}\end{matrix}\right\}$ and nearly at right angles to line. The same abbreviations also apply with reference to the direction of progress relatively to the wind.

until the recorder announces that the readings at that station check properly. The recorder uses, as a short method of computing the mean of the three thread readings, the fact that the difference of the upper and lower intervals divided by three is the correction to be applied with the proper sign to the middle thread reading to give the mean of the three.

A party which has just returned from the field after having completed nearly 120 miles of single line per month for over five months has turned in record books in the form indicated above, in which every value has been checked by applying the same process as used by the recorder. In addition to this the sums of the mean rod readings at the bottom of each page have been checked by adding the second column of each page and dividing by three, so that these sums have been derived three times, and by two independent processes, and two or three different men.

But little explanation is needed in connection with the computation form, Table No. 28. The forward line from B. M. 68 to B. M. *G*, on this form, is that for which the record is given.

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TABLE

ABSTRACT OF SPIRIT-

State, Tennessee. Instrument, Level No. 8. Rods, *V* and *W*.

Date.	From B. M. to B. M.	Distance in kilometers.	Difference of Elevation.			Discrepancy.	
			Forward line.	Backward line.	Mean.	Partial.	Total accumulated.
			m.	m.	m.	mm.	mm.
Aug. 28–29	65–66	1.279	— 8.3590	+ 8.3596	— 8.3593	—0.6	+47.1
" 29	66–67	1.302	+ 7.2327	— 7.2341	+ 7 2334	+1.4	+48.5
" 28–29	67–68	1.464	—16.3013	+16.3004	—16.3008	+0.9	+49.4
" 29–31	68–G	0.590	— 7.9650	+ 7.9640	— 7.9645	+1.0	+50.4
" 29–31	G–69	1.785	+22.6909	—22.6906	+22.6908	—0.3	+50.1
" 30	69–70	1.602	— 4.9882	+ 4.9920	— 4.9901	—3.8	+46.3
" 30	70–71	1.740	—20.2518	+20.2540	—20.2529	—2.2	+44.1
" 30	71–72	1.420	—15.4937	+15.4924	—15.4930	+1.3	+45.4

The fifth column on the left-hand page is derived from the fourth by using the sufficiently exact relation that 287 mm. subtended on the rod corresponds to 100 m. along the line, regardless of the lengths of the separate sights, the quantity $c+f$ on page 811 of the paper being ignored in both the determination of the stadia constant and its use.

The corrections for curvature and refraction shown in the first column of the right-hand page are those due to the differences of corresponding fore sights and back sights, no correction being necessary when the corresponding sights are exactly equal. The correction only becomes appreciable occasionally, and may be applied very quickly by the use of properly prepared tables and a rapid inspection of the record books. It seldom exceeds 0.1 mm. under actual conditions. It is important to note that this is in the main a correction for curvature, a quantity which is not uncertain, the uncertain refraction being upon an average about one-eighth as great as the curvature.

The level correction shown in the second column of the right-hand page is equal to the constant C (defined in the general directions for leveling) times the value in the sixth column of the left-hand page. This correction will very seldom exceed 0.3 mm. under actual conditions, and will be sensibly zero for most sections.

The third column gives the correction due to the excess of length of the rod at zero degrees, this particular rod being 0.28 mm. too long on each meter. The examinations of the rods made at the office show that the error of graduation is, with sufficient accuracy, proportional to the distance along the rod. The next column gives the correction due to the expansion of the rod from zero to the temperature of observation, computed with the known coefficient of expansion of the rods, namely,

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No. 29.

LEVEL RESULTS.

Observer, W. H. B. Computer, W. H. B.

No. of B. M.	Distance from B. M. No. 1.	Elevation above.	Locality.
	km.	m.	
66	110.585	423.8842	
67	111.887	431.1176	
68	113.351	414.8168	
G	113.941	406.8523	Stone post at Sunbright, Tenn.
69	115.730	429.5431	
70	117.332	424.5530	
71	119.072	404.3001	
72	120.492	388.8071	

0.000004 per degree Centigrade. The sum of the quantities in the third and fourth columns in any line gives the correction due to the excess of length of the rod at the temperature of observation. For these particular rods, which are long, even at zero, the correction in each of these columns will always have the same sign as the measured difference of elevation.

The last four columns on this form are for use whenever special studies are to be made to determine if possible the sources of the principal errors of leveling. It is in order to note in the last column that the time of the backward and forward runnings of any section have no fixed relation to each other. The two runnings are sometimes made on the same day, sometimes on different days, and in some instances they both occur in the forenoon, at other times both in the afternoon, and frequently they occur in opposite halves of the day. Any long portion of the line will show corresponding forward and back measurements having all possible relations to each other as to the time of day.

Table No. 29 is an abstract of results, and is essentially a summary and combination of the values derived on the computation form. The first form, Table No. 28, is discontinuous, showing results from separate sections, while this abstract, Table No. 29, is continuous, and is substantially the form in which the results are published.

The discrepancies between the forward and back lines are shown in the last two columns of the left-hand page. The accumulated discrepancy up to Bench-mark 72 is 45 mm. on 120 km., or at the rate of slightly less than $\frac{1}{5}$ mm. per kilometer of line run. It may be remarked that the total discrepancy had only increased to 53 mm. at the end of the line, 38 km. farther on.

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TABLE No. 30.—Determination of C, 8.20 a. m., August 28th, 1900.

Left-hand page. *Right-hand page.*

Number of station.	Thread reading back sight.	Mean.	Thread interval.	Rod and temperature.	Thread reading fore sight.	Mean.	Thread interval.
A	1 515 1 528 1 542	1528.3	13 14 27	*W*	0 357 0 462 0 566	0461.7	105 104 209
B.........	2 252 2 357 2 462	2357.0	105 105 210	*W*	1 276 1 288 1 301	1288.3	12 13 25
Corr. for curv. and ref.		0461.7 2818.7 — 0.8	419 52 367			1528.3 2816.6 2817.9	
						367) — 1.300(— 0.004 = C	

Table No. 30 is a sample of the record and computation of the determination of C, the constant expressing the relation between the tangent of the level vial at its middle point and the pointing line of the telescope, will be understood without difficulty by reference to the statement of the method of determination of C in the general directions for leveling, and by noting the way in which quantities have been transferred from the right-hand to the left-hand page and *vice versa*. The correction of — 0.8 mm. for curvature and refraction is applied to the sum of the two distant rod readings, the correction for either one being — 0.4 mm. The curvature is not appreciable for the near rod readings.

Contrast of Methods.—A comparison of the present Coast Survey method, just described, with the author's method, indicated on pages 866 and 871, will show that there is just twice as much observing per station in the latter method as in the former, the three lines of the reticule being read against each of the rods twice in the author's method and only once in the Coast Survey method. It is still more important to note, however, that there is much less manipulation required in the Coast Survey method than in the other, the additional manipulation in the author's method being at each station the placing of the striding level in position and taking it off again after observation, reversing the striding level twice and reversing the telescope twice at each station. It is the writer's opinion that the additional time spent at the station for these additional observations and additional manipulations tends to reduce the accuracy of the observations by increasing the magnitude of all errors which are a function of the elapsed time at the station, the most prominent of which are errors due to changes of temperature in the instrument. In addition to this it is probably true, as a general proposition, that the more an instru-

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ment is handled during a set of observations the less accurate are the results obtained.

In the author's method reliance is placed upon reversals of the telescope and striding level to eliminate the instrumental errors. In the Coast Survey method reliance is placed definitely upon the near equality of corresponding fore sights and back sights. The corrections which result from the small measured differences of corresponding sights are found to be so small that it is hardly worth while to apply them. The time spent in applying these small corrections and in determining the constant C each day in the field is probably little more than 1% of that required in the author's method for the thousands of reversals of the striding level and telescope in the field.

Other points of contrast between the two methods will be touched upon later in this discussion.

Reason for Change in Coast and Geodetic Survey Method of Leveling.—Beginning with the year 1899 the Coast and Geodetic Survey has used a radically different method of leveling from that which had previously been followed in that organization for many years. It is important, therefore, that the reasons for this radical change should be made known.

The old method of observation* fulfilled the author's doctrine that the method of leveling "becomes more complicated and requires more painstaking in proportion to the accuracy required" (page 784), and that "The most reliable results in precise leveling are undoubtedly to be obtained by careful and systematic observations designed to prevent and eliminate errors directly in the observations." The method involved the use of a target rod, and in that respect was radically different from the author's method, but it closely resembled it in that both the striding level and the telescope were reversed during the readings upon each rod at each station. The amount of observing at each station exceeded considerably that necessary in the author's method. In fact, the method advocated by the author may be said to be a mean in degree of complication and the number of readings required at each station between the old C. & G. S. method and the present C. & G. S. method.

As the number of connections of the level lines run by the old C. & G. S. method with tidal determinations, with other level lines of the same kind, and with level lines run by other organizations, increased, it became more and more evident that the real accuracy of such leveling had been greatly overestimated; and that the internal evidence of the observations furnished by the agreement of the two or more runnings of the same section with each other was an entirely fallacious indication of the accuracy. In 1898 so much evidence of this kind

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* This method is described in Appendix No. 15 of the C. & G. S. Rep. for 1879, pp. 202–211, and again in Appendix No. 8 of the C. & G. S. Rep. for 1898–99, pp. 416–418.

Mr. Hayford. had accumulated that there could be no doubt of the desirability of a special investigation to determine where the difficulty lay.

On November 29th, 1898, the Superintendent of the Coast and Geodetic Survey appointed a committee of four* to consider the subject of precise levels and in particular to investigate "The accuracy of various methods, their relative freedom from systematic errors, and their relative quickness, cheapness and facility of reduction of the observations." This committee met for three or four hours on nearly every working day from that date until their report was submitted on February 9th, 1899. All the results of precise leveling published up to that date in the United States were examined, as well as much of the general American literature on the subject of precise leveling, and some of the principal European publications on the same subject. For their convenience all the levels illustrated in the author's paper were brought to Washington for direct examination. As a result of this extensive study of the facts in the form of published results and of the various opinions of individuals expressed in the literature examined, and of direct examination of the instruments advocated by various parties, the committee made almost unanimous recommendations which led to the abandonment of the old method of leveling and the modification of the instrument itself. Two of the main conclusions reached by the committee and upon which their recommendations were based were that the principal errors in the old Coast and Geodetic Survey leveling were systematic temperature errors following a certain law, which is stated more fully further on, and that the leveling by the Corps of Engineers with Kern instruments and a very simple method of observation was of at least as high a degree of accuracy as that of the C. & G. S., using a much more complicated and laborious method of observation and computation.

Adjustment of the Precise Level Net.—It fell to the lot of the writer, as a part of his regular duties, during the first half of the present year, to direct the compilation of the results of precise leveling in the eastern half of the United States, and the adjustment of the complicated net-work formed by such lines. In the course of the work of compilation some new information became available in addition to what the committee had used. Before making the final adjustment of the net it was necessary to review carefully the work of the committee, to re-examine the evidence which they had considered, and to study the new evidence and test the conclusions of the committee in every possible way. It was of the highest importance in making the adjustment that the relative accuracy of the different kinds of leveling should be ascertained, and that the systematic errors of each kind of leveling should be specially investigated. The investigation thus made as a preliminary to the adjustment of the level net confirmed the committee's conclusion fully in regard to the systematic temperature error affecting the old C. & G. S. leveling, and showed incidentally that the work done by the Corps of Engineers was of a very much higher degree of accuracy than the old work done by the Coast and Geodetic Survey. It thus furnished new evidence that the recommendations of the committee in regard to change of method and instrument were correct. At the time the adjustment was made three parties had already completed a season's work with the modified level and the new method and these results were also available. Mr. Hayford.

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* John F. Hayford, Isaac Winston, J. J. Gilbert and A. L. Baldwin.

The net-work of precise leveling resulting from the compilation, and which was adjusted, is shown in Plate XLVII. The line symbols indicate the organization which did the work and in a general way the kind of leveling involved. The figures inside each circuit show the closing error of the circuit and the circumference of the circuit not including water leveling along tidal waters. A plus value for the closing error of the circuit indicates that the elevation, carried continuously around the circuit in a counter-clock-wise direction, is too great at the closing point. The approximate closing error, expressed in millimeters per kilometer, can be obtained at a glance by dividing the upper value in each circuit by the lower.

No argument is needed to show that to secure the highest possible degree of accuracy in the elevations assigned to the 4 000 bench-marks connected with this net it must be treated as a whole, and not as an aggregation of separate lines, as it has been in the past. It is evident that the errors of closure should be distributed so as to make all the closures disappear and make all lines agree at junction points. The best method to be used in making such an adjustment is not self-evident. It is a matter of judgment rather than of fact. After an exhaustive study of the matter it was decided to use the least square process of adjustment but to supplement it and check the assumptions upon which it is based as frequently as possible by other methods of investigation.

In the Coast and Geodetic Survey Report for 1898–99 is given a full statement of the compiled facts and such a full statement of the processes of adjustment as will enable any engineer to judge for himself as to the trustworthiness of the results. This will be of especial value to the engineer who is interested in precise leveling, as such. For the engineer who is interested in the results rather than the processes there is also given a complete list of the adjusted elevations of more than four thousand permanent bench-marks connected with the level net and also a list of such short descriptions of these bench-marks as will enable the engineer to find them. These two lists are for convenience provided with an alphabetical index. This appendix* was at the date of writing (Oct. 29th, 1900) in the hands of the printer,

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* No. 8 of the Report for 1898–99, p. 347 *et seq.*

Mr. Hayford. and it was expected that it would be ready for distribution in November, 1900. Any interested engineer may obtain a copy by writing to the Superintendent of the Coast and Geodetic Survey, Washington, D. C.

The Temperature Error in the Old Coast and Geodetic Survey Leveling.—The character and amount of the temperature error discovered in the old C. & G. S. leveling is of special interest in this discussion because the author concedes that the errors due to temperature and atmospheric conditions are among the most dangerous errors to be encountered in precise leveling (pages 812, 843 and 893) and because his method and instrument seem to leave the way open to such errors.

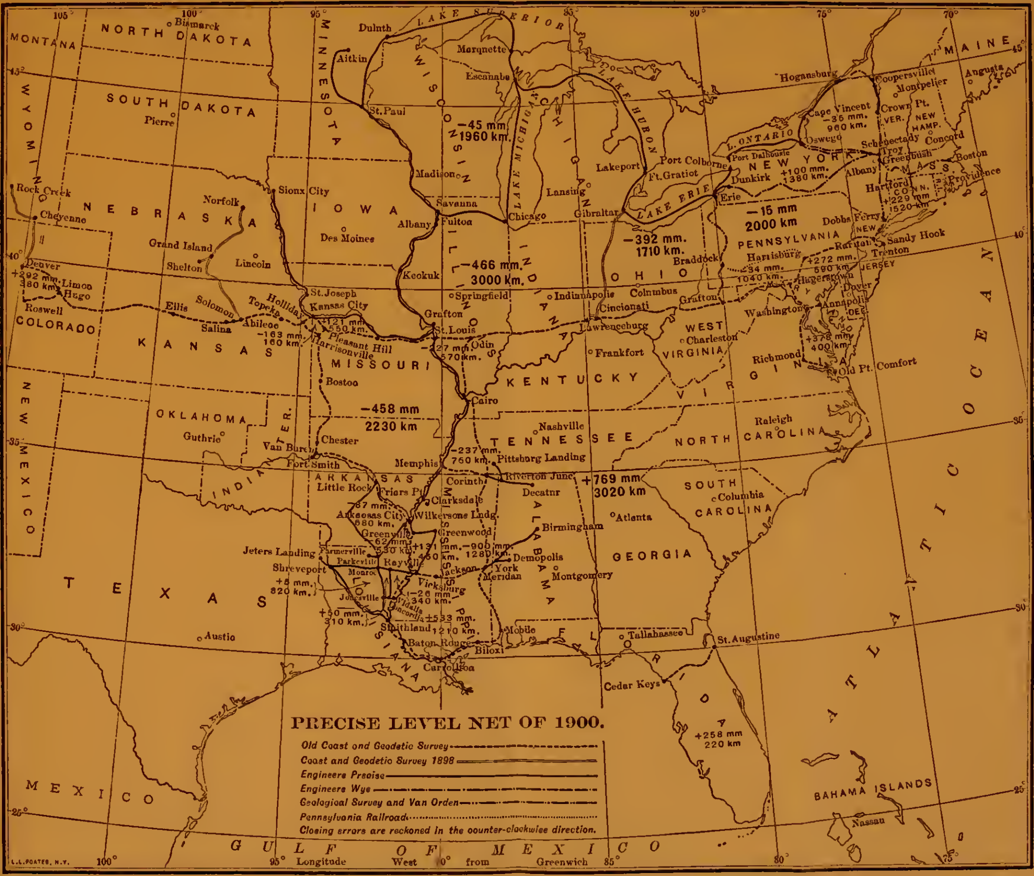
The committee report, confirmed by later investigation, indicates that a horizontal surface, as defined by C. & G. S. leveling previous to 1899, is always tipped up with reference to the true horizontal surface, the rotation being about a line 12° north of west or south of east and the inclination being such that the southwestern part of the surface is too low and the northeastern part of the surface too high, regardless of the direction in which the leveling actually progressed. According to this law a C. & G. S. level line running in a direction about 12° east of north will give elevations which run too low at a maximum rate; a line in the opposite direction will run too high at a maximum rate; and in the two directions at right angles, namely, 12° north of west and 12° south of east a line will not be subject to a systematic tendency to run either too high or too low. It may be well to note here that an error of this form will not be detected by re-running the line in the opposite direction, for if the forward line runs too high in going southwestward, say, the backward line running to the northeastward will run low by the same amount, and the two lines will show no divergence.

The proofs for this law, brought forward by the committee, did not involve any use of the principles of least squares. They were based simply upon the discrepancies developed when lines were run between tide gauges or between points connected independently by other lines of levels run by some other method. The main reliance was of course placed upon the first line of evidence.

Several preliminary adjustments of the precise level net were made before a final adjustment was attempted. These preliminary adjustments showed that the C. & G. S. lines persistently needed corrections in accordance with the law of error stated above. The same tests were also applied by the committee, and again in the preliminary adjustments, to the leveling by the Corps of Engineers, and in every case indicated that there was no appreciable systematic error in the Engineer Corps leveling corresponding to that in the C. & G. S. leveling.

It might be contended that the evidence thus furnished by the preliminary adjustment was not valid, as it involved the assumption that

PLATE XLVII.
PAPERS AM. SOC. C. E.
NOVEMBER, 1900.
HAYFORD ON PRECISE SPIRIT LEVELING.



PRECISE LEVEL NET OF 1900.

Mr. Hayford.

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the Gulf of Mexico is at the same elevation as the Atlantic, whereas it has been claimed that it is considerably above. It is desirable, therefore, to obtain some check on the reality of the systematic error which is independent of any such assumption. In the level net shown on Plate XLVII there are eighteen circuits, of which the C. & G. S. leveling previous to 1899 form a part only, the remainder being either spirit leveling of some other kind or water levels. Only one of these circuits, namely, that given by the level lines from St. Augustine to Cedar Keys, Fla., and the water levels from Cedar Keys to St. Augustine through the Straits of Florida, has a closing error which is affected by the assumption as to the relative elevation of the Gulf and the Atlantic. The remaining seventeen closures are independent of any such assumption. Of these seventeen, fourteen have closing errors of the sign which would be accounted for by assuming that the closing error in each case is due entirely to the above systematic error in the portion of the circuit run by the C. & G. S. previous to 1899. An additional circuit has since been closed which also agrees with the fourteen, making in all fifteen cases out of eighteen. For example, in the circuit, Cairo—Odin—St. Louis—Cairo, the eastern and northern sides of the circuit were run by the C. & G. S. According to the law of the supposed systematic error the line from Cairo to St. Louis, *via* Odin, should run considerably low, causing the closing error of the circuit to be negative. The actual closing error is —227 mm. and the circumference of the circuit 570 km.

The reality of the supposed law of systematic error having been satisfactorily established by a purely inductive method, without reference to any theory as to its cause, the next step in making the adjustment of the level net was to derive a numerical expression for the error and to apply the proper corrections to the various lines. It was found that the correction to the elevations on a line running 12° west of south was —1.25 mm. per kilometer, and that it was +1.25 mm. per kilometer in the opposite direction. For a line running in any other direction the correction required is proportional to the cosine of the angle between the line and the direction stated above. This maximum correction of 1.25 mm. per kilometer corresponds to a vertical angle of only 0.33 of a second of arc, less than one-sixth of a division on the level vials ordinarily used, one division being from 2 to 3 seconds. The minuteness of this correction should be kept in mind when considering the possible explanation given below.

It will probably be conceded, by all who are familiar with instruments of precision, and with the particular instruments herein described and the conditions under which they are used in the field, that unequal though small changes of temperature are continually taking place in different parts of the leveling instrument while in use; that these unequal changes of temperature produce continual small

Mr. Hayford. changes in the relative positions of the different parts of the instrument; that all portions of the instrument on the side from which the greatest amounts of heat are being received tend to assume higher temperatures than those on the opposite side, and that in general the instrument receives more heat from the side toward the sun at any given time than from other directions, even though the immediate source of heat is not the sun (from the direct rays of which the instrument is always protected), but the inner surface of the tent or umbrella, the surrounding ground, etc. Changes of the kind just outlined occurring in parts of the instrument which are below the line of collimation of the telescope can be shown to have but little influence upon the final results, since they affect both the line of collimation and the level vial alike, and may be considered as simply influencing the stability of the instrument.

On the contrary, similar changes taking place above the line of collimation of the telescope can be shown to have marked systematic and cumulative effects.

One effect of unequal changes of temperature occurring above the line of collimation is to change the angle between the tangent to the level vial at its middle point and the line of collimation. As soon as the telescope and striding level are placed in a given position the parts which are toward the source of heat (the sun) tend to assume a higher temperature than the opposite parts, and the effect of the unequal expansion of the collars of the telescope and of the legs of the striding level, and of distortion of the vial itself, is to cause the bubble to crawl slowly toward the source of heat. Thus the bubble always tends to be nearer the sun than it would be if all parts of the instrument were always at the same temperature. The ultimate effect of this is to make the corrected rod reading too small when taken upon rods toward the sun from the instrument, and to make readings taken upon rods away from the sun too large. These errors combine in their effect upon the computed elevations, and tend to make the elevations carried toward the sun too great, and *vice versa.*

It may be remarked in passing that this explanation also applies to the author's method of leveling. If the bubble tends to crawl toward the sun on account of expansion of the sun-ward end of the striding level and of the sun-ward collar, and on account of direct distortion of the level vial, and is held back from such movement by use of the micrometer screw when taking readings on a rod toward the sun, the rod reading is necessarily too small, the line of sight having been inclined downward by the act of holding back the bubble. The reverse will be true in reading upon a rod away from the sun. These errors will combine as indicated above and make all elevations carried toward the sun too great, and *vice versa.*

Is this explanation quantitatively sufficient to account for system-

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atic errors which were found in the old C. & G. S. leveling? Do the laws corresponding to this explanation agree with the actual results of the leveling? As to the first question it may be stated that the changes of temperature required are exceedingly small, differences of less than 0.1° Cent. between the two collars or two legs of the striding level being sufficient to account for 1 mm. per kilometer. The following paragraphs are given in response to the second question.

During the progress of the leveling along a given line the sun is steadily changing in azimuth during each day and the temperature error at present under consideration is necessarily undergoing corresponding changes. The temperature error remaining in the final result from a long line of levels should be that corresponding to the average direction of the level line and the average effective azimuth of the sun during the hours of observation. This average effective azimuth will be, for C. & G. S. work, a little west of south, both because the afternoon period of observation is upon an average slightly longer than the forenoon period and because the amount of heat reflected from the ground and other objects toward the instrument from the direction of the sun will be much greater during the comparatively dry afternoon hours than during the moist morning hours. This agrees with the fact stated above that the maximum systematic correction occurs on an average for a line 12° west of south or east of north.

These systematic temperature errors should be expected to be much smaller in cloudy than in sunny weather; much smaller on a line run in the shade of trees or over grass than on a line unshaded from the sun or over the bare ballast of the railroad track; should be expected to depend intimately upon the care taken to protect the instrument from the sun and from reflected heat from surrounding objects; and should be expected to increase as the length of time that the instrument stands at the station is increased. The resulting systematic errors on various lines due to this cause will, therefore, be expected to vary widely in magnitude.

On certain of the lines run by the C. & G. S. previous to 1899 the double simultaneous method was used. On these lines the two rods were usually known as *P* and *Q*. One of the double lines was run entirely with the *P* rod and the other with the *Q* rod, and at each instrument station all readings upon the *P* rod were taken before the corresponding readings on the *Q* rod. The observations on the *Q* line were, therefore, always taken later than those on the *P* line, and if the above theory in regard to the temperature errors is correct it should be true that upon an average the *Q* line should have a larger error than the *P* line, the differences of temperature having had more time to accumulate before the observations were made. It happens that there are four such lines, aggregating a total length of 1 000 km., for

Mr. Hayford. which the corrections are known with considerable accuracy. In each of these cases the Q line is farther from the truth than the P line, and the errors of both lines have the same sign, in accordance with the theory advocated.

If the Q line is always farther from the truth than the P line, the divergence between the P and Q lines should be systematic with respect to the direction of the line, just as the error of either one is systematic with respect to direction, that is, the sign of the discrepancy $P-Q$ should be plus for a line running a little east of north and minus for a line in the opposite direction, and should approach zero for a line running nearly at right angles. As a further test upon the theory this supposition was examined on all the available lines leveled in this manner, nearly 2 400 km. in all, and 57% showed a discrepancy $P-Q$ in agreement with the theory, and 43% disagreed. The discrepancies of those lines which agreed with the theory were about three times as large as those which disagreed.

A still further test of this same matter of the relation of the discrepancy $P-Q$ and the direction of the line was made by examining the same lines by separating them into sections at points where there were marked changes in the general direction, and comparing the rate of divergence of the P and Q lines on each section with the rate of divergence on the preceding and following section. If the theory advanced is correct, whenever the direction of the line changes in such a way as to approach the direction 12° west of south the minus rate of the divergence between the two lines should increase; and if the change of direction is such as to make it approach 12° east of north, the plus rate of divergence should increase. The examination showed that 82% of the leveling so examined agreed with the theory, and only 18% disagreed.

It is important to note that the magnitude of this systematic correction has been determined by treating several thousand kilometers of leveling done under ordinary conditions, and that the above indirect tests of the theory are also based upon thousands of kilometers of such leveling. The conclusions just stated must, therefore, be given heavy weight in comparison with any deductions from a few experimental observations over short lines and covering but a few days or hours.

It is important to note that the same tests being applied to the leveling by the Corps of Engineers, in which a simple method was used involving but a short observing period at each station, failed to indicate any appreciable systematic temperature error. The author's method of observing is intermediate between the old C. & G. S. method and the Engineer method, and the writer, therefore, believes that his leveling is probably subject to a systematic temperature error which is considerably smaller than that in the old C. & G.

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S. leveling. The construction of the instrument used by him is also such as to warrant the supposition that a temperature error of the kind indicated must exist in the results.

The reason for the extraordinary efforts to eliminate if possible the temperature error, in designing the new instrument, should now be apparent. The substitution of the nickel-iron alloy, with a coefficient of expansion about as small as that of pine, in the place of the bell-metal and brass formerly used in the construction of the telescope and striding level, the increased protection of the level vial by countersinking it into the telescope and surrounding it by a dead-air space enclosed by heavy metal and glass walls, and the placing of the level vial as close as possible to the line of collimation, are all features designed to eliminate the temperature error in the 1900 instrument. The notes indicated in the last four columns of the form shown in Table No. 28, were taken for the express purpose of determining whether the temperature error was still appreciable in the new leveling. If the forward and backward runnings on a certain section of the line were made at such times that in both cases the direction of progress was directly toward the sun, the effect of the temperature error being to make both lines run high toward the sun, the discrepancy $B - F$ between the two runnings would tend to be of the minus sign. Similarly, if in both cases the leveling progresses away from the sun, the sign of $B - F$ should be plus. In short, if the temperature error still existed it should be possible to predict the sign of the divergence of $B - F$ for certain cases, and the actual signs and magnitudes of the discrepancy $B - F$ might, therefore, be used to detect the temperature error. Such a test was applied carefully and in detail to each of the three lines run in 1899. It indicated that even with the instrument of the intermediate type used during that year the temperature error, if it existed at all, was so small as to escape detection.

This particular form of test was not available in connection with the old C. & G. S. leveling, because the necessary notes as to time of day and direction of the line and weather conditions were not taken.

Minor Comments.—The writer agrees completely with the author in regard to the desirability of simultaneous reading of the rod and bubble when it is desired to obtain either accurate or rapid observations (page 824). The writer also agrees with the comment made on the French bubble-reading device (page 791) to the effect that it does not accomplish satisfactorily the primary object for which it was designed, namely, to enable the reading of the bubble and rod to be made simultaneously. It may be noted that the reading device on the 1900 C. & G. S. level makes the reading of the rod and bubble as nearly simultaneous as is possible, it being so constructed that the distance between the eyepiece of the telescope and the eyepiece of the reading device is adjustable to fit the distance between the eyes of the

Mr. Hayford. observer using it; the focus of the reading device is adjustable and no movement of the eyeballs is necessary when the attention is changed from the rod to the bubble. In the opinion of the writer, the inclined mirror does not accomplish the purpose so well as the 1900 reading device, for the reason that the observer must change the direction of his line of sight in looking from the image of the bubble in the mirror to the rod, or *vice versa;* that he is likely to be troubled by distracting images of surrounding objects in the inclined mirror, and that the observer is forced to hold his head in such a position that the two eyes are nearly in the same vertical plane. He must, therefore, hold his head on one side, and is forced to set up the instrument several inches lower than is necessary when using a reading device which allows him to stand in a natural erect position.

The author's point, that the ordinary Y-level is very imperfect in principle and is not conducive to quick work, seems well taken (pages 787, 797). The plan used on all precise levels, of mounting the telescope in such a way that it is controlled by a micrometer screw under the eye end, is conducive to rapid work, and may be introduced to advantage on ordinary instruments. The same statement is true of the various devices for reading the bubble without moving away from the eye end of the telescope. The use of a direct-reading rod or "speaking rod" in the place of a target rod is also conducive to rapidity. The writer believes that any class of leveling can be done more rapidly with the C. & G. S. 1900 level, or an instrument of the same type provided with a less sensitive vial for rough work, and by using direct-reading rods, than can be done with the ordinary Y-level and target rod. The observer will usually read the three lines against the rod much more quickly than he can indicate to a rodman the point at which the target must be placed to obtain the same accuracy. The manipulations of the instrument can certainly be made more rapidly. In support of this opinion, attention is called to the statements of the actual performances of the 1899 and 1900 C. & G. S. levels given under the heading "Speed and Accuracy of Coast and Geodetic Survey Leveling, 1899–1900." Page 1156.

The author considers the fact that the horizontal axis in the Mendenhall instrument, about which the telescope rotates under the action of the micrometer screw, intersects the vertical axis of the instrument, an advantage, and implies (pages 789, 790 and 794) that when the horizontal axis is not so located there are appreciable changes in the height of instrument between corresponding fore sights and back sights on account of the re-leveling. This argument against placing the horizontal axis in the usual position has frequently been advanced by others. Is it a valid argument? The practice among C. & G. S. observers is to notice at the beginning of the day's work the reading of the micrometer head for which the telescope is at right angles to the

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vertical axis; in other words, such a reading for the micrometer that the bubble of the level will remain in a fixed position when the instrument is reversed in azimuth after being accurately leveled up. After once getting this reading in mind, and it will ordinarily remain constant within two or three divisions of the micrometer all day long, he places the micrometer at that reading when the instrument is set up and then finds that when the change is made from the back sight to the fore sight, or *vice versa*, that the reading of the micrometer head needs to be changed by something less than ten divisions and often not more than two or three. If the total change is even as great as eleven divisions, corresponding to about 30 seconds of arc, the height of the instrument is changed by about one-seven-thousandth of the distance from the vertical axis to the horizontal axis, or, in the case of the 1900 level, by about $\frac{1}{70}$ mm., a quantity which is negligible for a single station, especially as it is as likely to be of the contrary sign to the same sign at the next station. To guard against this very small and compensating error by introducing new difficulties for the instrumentmaker by requiring him to make the vertical and horizontal axes intersect seems to be an error of judgment.

Figure 8 on page 806 and the two paragraphs following it contain unimportant mistakes which are puzzling to the reader until he finds that they are simply blunders. The only ray of light passing through the optic center which suffers no refraction is, of course, the ray passing along the line $C\,C'$ of the figure, which enters and emerges from the lens along normals to the surfaces. Any other ray passing through the optic center, such as the ray $B\,E\,O\,E'B'$, is refracted at each surface, but passes out along a line parallel to the original direction of the ray. The statement in the first paragraph at the top of page 807 makes two separate rays of light $B\,B'$ and $A\,A'$ pass along the same path $E\,E'$ within the lens, and different paths outside, an impossible case.

Table No. 3 is given to show that the effect of solar attraction is indicated by the author's leveling in 1898 and 1899. If the solar attraction were appreciable there should be a large preponderance of minus signs in Group 1 of that table, and of plus signs in Group 2, while Groups 3 and 4 should each show no well-marked preponderance of either sign. As a matter of fact, the preponderance of signs in Groups 1 and 2 is no more marked than in 3 and 4, and it does not seem reasonable, therefore, to assert that the table contains any evidence of solar attraction.

The author maintains that a reversible striding level is an absolute necessity on a precise leveling instrument. He states, as his reason, that "no reliance should be placed on the capability of a level tube for holding its horizontal adjustment," and, that "The only rational elimination of this error can be accomplished by taking observations for each sight with the level tube direct and reversed." Such a state-

Mr. Hayford. ment is an indication of the quality of the particular instrument with which the author is most familiar. The C. & G. S. levels do not behave in the manner indicated. One of the 1900 levels was carefully put in adjustment at Washington in July, 1900, and shipped by express to a point in Kentucky. The observer there, on beginning work with it, found it to be still in adjustment. He began his observations on July 24th without having touched an adjusting screw and continued without making any adjustment until September 7th. During that period the value of C never exceeded 0.005 until September 7th, when it jumped to +0.015. The value 0.005 for C means that the line tangent to the level vial at its middle point makes an angle of approximately 3 seconds with the pointing line of the telescope. The instrument was adjusted on September 7th and from that time until October 20th C exceeded 0.005 only once, and then was found to be 0.006, only. The mean value (algebraic) of C during the period September 8th to October 20th was + 0.002, or but little more than 1 second of arc. C was determined regularly on every day on which observations were made. If C equals 0.005, the correction due to this error of adjustment when the difference of a fore sight and the corresponding back sight is 10 m., that being the maximum difference allowed, is only 0.1 mm. In the computation it is proposed to apply the corrections whenever appreciable, upon the assumption that the error is constant for one day at a time. When the total range of variation in the adjustment does not exceed 6 seconds of arc for weeks at a time, as in this instrument, and the test of the adjustment is made on every day and at various hours of the day, will the author contend that the accuracy of the leveling has been appreciably decreased by substituting such a fixed level for the striding level?

The other 1900 instrument behaved nearly, but not quite, as well as this one. One of the 1899 C. & G. S. levels, which was still in use during the present year, shows a similar behavior. It was in use from May 8th to September 12th, during which time 225 miles of double line of leveling were completed. Its error of adjustment was determined twice during each day of observations. It was adjusted only once during the season. The error of adjustment exceeded 3.4 seconds only six times during the whole season.

Especial attention is called (pages 828–829) to the necessity of accurately centering the objective and of insuring that the sliding tube carrying the eye end moves in a straight line. This is, of course, more important for a level telescope of the non-reversible type used in the 1900 C. & G. S. instrument than for the reversible type of telescope. It is necessary to insure within certain limits in the non-reversible telescope that the point in the reticule defined by the middle thread, or rather the mean of the three threads, moves in a straight line passing through the optical center of the objective during the process of focusing. A little investigation shows that it is not difficult to secure this condition, within the required limits, in the instrument shop. It is important, however, to note that when the reticule in such a non-reversible telescope has once been adjusted to the proper position, that this adjustment must not be disturbed in the field. All field adjustments must be made by moving the level vial and not by moving the reticule. Mr. Hayford.

On page 838, a possible heaving or settling of the instrument or rods, as an explanation of the systematic differences often noted between forward and backward lines, is dismissed quickly without an adequate discussion. It is apparently assumed that if the turning point pins "are scarcely susceptible to any heaving or settling of sufficient magnitude to be readable with an instrument, even at a very short range," that it is proved that no appreciable systematic errors can arise from the cause under consideration. The systematic divergences between forward and backward lines, which have been accounted for frequently in the literature of leveling as having resulted from rising or settling of the rod supports or of the instrument, have seldom exceeded 0.25 mm. per kilometer of line run, and have more frequently been less than 0.1 mm. per kilometer than more. To account for an error of 0.1 mm. in a single kilometer, supposing that there are seven stations (average sight 71 m.), if it be assumed that each rod support (7) and each instrument support (7) had a systematic tendency to settle (or rise), requires that each movement should be on an average 0.007 mm. if they are all of the same sign. This quantity is not readable with a leveling instrument, but is sufficient to produce the error for which an explanation is sought. To assert that the rod and instrument supports are not subject to changes of that magnitude is to assert that they have an exceedingly high and improbable degree of stability. To account for an error of 0.25 mm. in a single kilometer by movements of the rod supports alone, the systematic movements of the instrument being eliminated by the method of observation, which is the case if half of the fore sights are taken before the corresponding back sights, requires a systematic settling (or rising) of less than 0.04 mm. at each point, a quantity which is still not readable on the rod with the leveling instrument. Is it not true that this source of error is sufficiently dangerous to make it imperative that all lines should be run in both the forward and backward direction and the mean taken, if the highest degree of accuracy is desired?

The requirement, stated without modification on page 857, that the recorder and the rodmen of a leveling party should be college graduates is at least open to question. The computation required of the recorder consists simply of adding and subtracting, and dividing by two or three. It is essential that he should be a man who is careful and conscientious, and who can make such simple computations as are required of him with accuracy and rapidity. The rodmen must be

Mr. Hayford. men, or youths, who will take an interest in the work and obey orders. All must be willing to hurry, and each must have the physique to stand the work and the stomach to stand the changing fare. These qualities can be found without difficulty among those who have never been to college, and to require such an education is surely arbitrary.

On page 860 the statement is made that "On some recent Government work, a system of single lines has been adopted with the expectation of checking or closing the work by leveling in large polygonal lines forming a net."

This statement is followed by a prediction as to the errors which would develop in such a case. The only recent work, within the writer's knowledge, which has been done in the manner stated is a portion of a line run in 1899 between Gibraltar, Mich., at the west end of Lake Erie, and Cincinnati, Ohio. Three different portions of this line were run as long loops by leveling continuously southward along one railroad and then returning to the starting point along another parallel railroad or canal towpath. In each case the leveling was carried continuously in a counter-clock-wise direction around the circuit as a single line. The lengths of the separate circuits were 82 km., 112 km. and 87 km., and the errors of closure were respectively —4.9 mm., + 9.0 mm. and + 9.3 mm. Moreover, these three circuits were broken into smaller circuits by six cross-lines at points where the two railroads, or the railroad and towpath concerned, drew near together. These cross-lines failed to develop the existence of any "serious local undulations," the nine small circuits showing the same absurdly small closures as the three large circuits. It is interesting to note that the observer on this line believes most thoroughly that the principal cause of a systematic tendency to run high (or low) is usually the settling or rising of rod supports.

Rods.—It is objected that the paraffining of level rods causes the wood to become soft, prevents the perfect adhesion of paint and increases the coefficient of expansion 50% (page 795). The Coast and Geodetic Survey has had paraffined rods in continuous use since 1895, and its experience does not justify any one of these criticisms. The strongest objections to paraffined rods seem to come from those who have used them but little, if at all, or from instrument makers who are not disposed to take up a novelty.

The symmetrical cross-section of the rod which is used by the C. & G. S. has a decided advantage over the T-shaped cross-section, in that the rod is less likely to warp. It has the apparent disadvantage of affording too narrow a front surface for any complicated graduation.

The discussion of pins *versus* foot-plates is dismissed with a single sentence (page 800), upon the ground that the foot-plates "are considered entirely out of date." Foot-plates are still in use in the Coast and Geodetic Survey, and have been continuously in use for many

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years. The discussion of pins *versus* foot-plates will probably be an endless one, as there are good points on both sides of the argument. It is the opinion of the writer that but little error in the ultimate results can be credited to either the foot-plate or the pin, provided each section of the line is run in both the forward and backward directions independently and the mean taken. It also seems clear to the writer that the decision between the foot-plate and the pin should be made to depend upon the character of the ground over which the leveling is carried, the pin being probably the better support on some kinds of soil and the foot-plate on others.

It is claimed (page 797) that the design of the rod shown in Figs. 1, 2 and 3 "is based strictly on the self-reading principle, and thus enables the observer to read, practically without counting anything, from the coarsest down to the finest graduation." It may be seen by consulting the illustrations of the C. & G. S. rod, Plate XLVI, that in its graduation an attempt has also been made to eliminate the necessity of counting. On each decimeter the 2-cm. point is marked by the upper edge of a white rectangle containing a figure, the 4-cm. by the lower edge of a black rectangle, the 5-cm. is marked by a white diamond, the 6 by the upper edge of a black rectangle, the 8 by the lower edge of a white rectangle, and finally the zero and 10 by the center of a white rectangle containing a figure. It is not necessary to count higher than 2 to identify any centimenter, even when the distinction between the black rectangles and the unpainted portion of the rod disappears. It is important to note that there are no marks on the rods having a least dimension of less than 1 cm., and that all areas of color, with the exception of the 5-cm. mark, are rectangular. The markings will, therefore, remain distinct for greater distances and more furious vibration of the air than will those of any design having smaller areas of color or many sharp points.

The author indicates on pages 797 and 836 his reasons for believing that a 2-mm. graduation should be furnished in addition to the centimeter graduation. In this opinion he does not stand alone, as the same principle is advocated by some European authors. The C. & G. S. rod carries no graduation finer than single centimeters, because it is known that under the actual conditions of work the 2-mm. graduation will be readable only on short sights. On such short sights occurring at the end of a section of the line when a connection is about to be made with a bench-mark, or in climbing a very steep grade, the centimeter graduations can be read with greater accuracy than ordinarily. To add a 2-mm. graduation for use in such cases is to strengthen the strongest part of the line, and is, therefore, a refinement which is of little value, although it does no harm if there is room on the rod for the additional graduation. It is pertinent to note that the rods used under the direction of the

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The writer fails to see the advantage of placing the zero of the graduation nearly 5 cm. above the foot of the rod. The C. & G. S. practice is to put the zero of the graduation at the foot of the rod, and no difficulty is found in maintaining that relation within narrow limits.

The author condemns the past practice of applying a constant rod correction for the whole season (page 834), and, going to the opposite extreme, advocates a direct measurement of the rod with a steel tape three times a day (page 800), or even at the beginning and end of each stretch (page 834). It would seem that the frequency with which the rod should be measured depends upon the accuracy with which the rod in question holds a constant length, and that the necessary frequency of measurement cannot be decided in the off-hand manner indicated on the pages cited. The various measurements of the C. & G. S. paraffined rods made between field seasons at the office during past years, and in the field once or twice a month during 1899 and 1900 indicate that after a paraffined rod has once been fully seasoned by actual use in the field or by exposure to temperatures as high as it will experience in the field, it will hold a constant length within a range but little greater than 1 part in 10 000 or 0.1 mm. per meter. This statement includes all variations due to changes in the humidity, or other causes, except changes of temperature, the measurements having been reduced to a fixed temperature by using the coefficient of expansion 0.000004 per degree Cent. The present C. & G. S. practice, of measuring the rods with great accuracy between field seasons and measuring them with a steel tape once or twice a month during the season, limits the possible errors from the cause under discussion to much less than one ten-thousandth of the difference of height measured. Under these conditions, daily measurements of the rods seem to be unwarranted.

During the process of seasoning the paraffined rods usually increase slightly in length.

Collar Inequality.—The author's statement, on page 843, that the commonly accepted method of determining the inequality in telescope collars is erroneous, and that "many of the constant errors frequently encountered in leveling operations and attributed to a great variety of causes, principally personal equation and settlement or heaving of instrument or rods," may be accounted for by this error, into which all who have dealt with this matter have fallen, is surely startling. The statement is made again, on page 851, that the usually accepted method of determining the collar-inequality "has already been explained and found erroneous." At various other points in the text the author indicates with emphasis the importance he attaches to this matter. Were the author's supposition true, not only would all who have dealt with

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precise levels be involved in confusion at the discovery of such a mistake, but so would several generations of astronomers who have used the same method, and set it forth in their writings, in connection with the determination of the inequality of the pivots of astronomical transits used for the determination of time. It is important, then, that the alleged proof of the error of the usually accepted theory should be carefully examined.

The first thing that attracts the attention of one who makes the examination is the startling array of assumptions which are stated to be necessary to prove the correctness of the ordinary procedure in determining collar inequality (page 830). The next matter that will catch the eye in a quick reading is the inaccuracy and confusion in the statements and formulas on page 831. In the figure, w is marked as a distance, and in lines 3 and 10 it is defined as an inclination or abstract number. ε is defined as an abstract number or inclination and t is stated to be a distance, and is so marked in the figure. The formula $w = \varepsilon + t$ is equivalent to a statement that a distance or abstract number is equal to the sum of an abstract number added to a distance, an absurdity. Similar absurdities occur at several points on the same page. Using this confusion as a clew, one would naturally look for some more serious error.

A careful examination will show that the author's whole argument is completely erroneous, and that the commonly accepted method of determining the inequality of collars is correct within attainable limits of accuracy. He has confused the measurement of the inequality of the radii or diameters of the two collars with a measurement of the effect of such inequality on the inclination of the telescope axis and the striding level. The quantity determined is usually referred to as inequality of collars, but by that is not meant inequality of the radii of the collars, but simply the effect of that inequality in producing an erroneous position of the telescope axis and the striding level.

The whole matter may be made clear by superposing Fig. 15 (*b*), page 831, on 15 (*a*), in such a manner as to make the two points O coincide, keeping both figures right side up. It must be kept in mind that these two figures represent in diagrammatic form a section at one collar through the striding level, telescope and cradle support in the plane of the contacts of those three bodies. The two circles representing the eye-end collar will coincide, after the superposition, O being the center of the eye end or larger collar in both cases. In the superposed figure the relative position of the "level tube" and cradle support will be that which they actually hold when the larger or eye-end collar separates them. The two small circles in the superposed figure, having centers at O' and O', show the two possible positions in which the smaller collar might be placed, first in contact with the cradle support and next in contact with the "level tube," Mr Hayford. supposing these two to maintain the relative positions which they had when the larger collar was between them. It is evident that under the action of gravity the smaller collar will take the lower of the two positions shown in the superposed figure and its center will then be a distance w or $O\ O'$ below the position which the center of the larger collar had occupied. Similarly, as the distance $O'\ A$ [of Fig. 15 (*b*)], A being a point on the striding level, is fixed, A will occupy a position $2\ w$, equal to $O'\ O'$, lower than it did when the larger collar separated the cradle support and the "level tube." In the reversal of the telescope under consideration the point A will have fallen a distance $2\ w$, and the corresponding point on the other end of the striding level will have risen $2\ w$, and the total change in inclination of the striding level, which will be measured by the movement of the bubble, will, therefore, be $\frac{4\ w}{L}$, L being the length of the striding level between its supporting wyes. Similarly, the change in inclination of the axis of the telescope, the line joining the centers of the two collars, will be $\frac{2\ w}{L}$ and the error in the inclination of the axis, due to inequality of collars, will be half this amount, or $\frac{w}{L}$, which is one-fourth the change of inclination indicated by the striding level in accordance with the usually accepted theory, and in accordance with the method of computation shown on the upper half of page 830. It may be noted that this is a direct proof, dealing with the quantity of which the measurement is actually required, and involves no consideration of the difference of radii of the two collars. On examination it will be found that it involves implicitly the assumption that the angular opening of the wyes of the cradle support is equal to, or nearly equal to, the corresponding angular opening of the wyes of the striding level. For, unless this were true, the two distances marked w in the figures would not be equal.

The author's treatment of the same observations would give a correction for inclination of the axis of the telescope due to inequality of the collars which is nearly two and a half times as great as the ordinary treatment,

On pages 872–875 is given an example of the record of observations made at a river crossing, and on pages 876–877 the claim is made that when these observations were reduced, by using a value 0.0635 for the inequality of collars, the results from the four crossings agreed very closely, within 2.4 mm., and that this would not have been the case if "the correction for collar inequality, found by the commonly adopted method of level tube and telescope reversals," had been used. This argument will not bear close examination. The author has failed entirely to apply any correction for curvature and refraction in his

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computation. It is essential to apply such a correction whenever forward and backward sights are very unequal as they are in the case in hand. The correction for curvature and refraction for a 215-m. sight (see Fig. 16) is 3.1 mm., for a 211-m. sight is 3.0 mm., and for a 22 or 23-m. sight it is 0.0 mm. Applying these necessary corrections to the observations, the results stand as shown in Table No. 31.

TABLE No. 31.

Line.	Excess of fore-sight.	Difference of Elevation.				
		Observed.	Correction for curvature and refraction.	Corrected for curvature and refraction.	Corrected, using 0.0635.	Corrected, using 0.0276.
	m.	mm.	mm.	mm.	mm.	mm.
1st direct D_1	+192.7	+123.8	+3.1	126.9	139.1	132.2
2d direct D_2	−188.6	+148.1	−3.0	145.1	133.2	139.9
1st reverse R_1	+188.6	+146.3	−3.0	143.3	131.4	138.1
2d reverse R_2	−192.7	+124.6	+3.1	127.7	139.9	133.0

The last column was computed by using 0.0276 mm. per meter as the correction for inequality of collars, that value being given on page 830 and stated to be the mean of twenty observations taken in the ordinary way. The last column but one shows the corrected values, using 0.0635, the author's value of the correction for collar inequality. It will be noted at a glance that the range of the four results is about as great in one case as in the other. The observations indicate that the true value of the collar inequality is between 0.0276 and 0.0635, as such an intermediate value would come closest to making the four differences of elevation agree. The remarkable agreement of 2.4 mm., shown on page 876, has now disappeared, and with it the force of the argument based upon that agreement.

It may possibly be contended that the correction for refraction should be neglected, as the refraction is a very uncertain quantity. The curvature, however, is not uncertain. It is positively known within very narrow limits. The corrections used herein would be increased slightly by neglecting the refraction, as that has been assumed to be one-eighth of the curvature and of the contrary sign.

It may also be claimed that, as the curvature and refraction are neglected in the determination of the inequality of collars, by the method advocated by the author and shown on pages 852-853, this neglect will produce errors of the same magnitude, and of the contrary sign, as those produced by the neglect just noted in the observations at the river crossing. Such an argument, however, is utterly fallacious, as the correction for curvature and refraction increases as the

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With the exception noted, namely, the neglect to apply the correction for curvature and refraction, the method shown in Table No. 9 seems to be correct, and should give a value of the collar inequality in agreement with that of the ordinary method by reversal of the telescope, except for unavoidable errors of observation.

The discrepancy between the various values of the collar inequality determined by the two methods seems to the writer to be evidence of wear in the instrument, or poor observation, rather than anything wrong in the theory. The value + 0.0235 mm. per meter is given for this correction on page 877, and + 0.0276 on page 830, both being determined by the usual method by reversals of the telescope in the wyes. The value 0.0624 is shown on page 853, and the value 0.0635 is used by the author on page 876. Finally, the river crossing treated on pages 872-876 indicates that the true value lies somewhere between 0.0635 and 0.0276. The great range of these values, and the fact that they are unusually large, is an indication that the concentration of the wear on the telescope collars at four small areas has produced the effect which should be expected.

Table No. 6 and the Conclusions drawn from it.—The importance ascribed by the author to the experiments indicated in Table No. 6 may be appreciated by noting the frequency and character of the references to it. According to his statement:

> "The important cumulative error is that produced by the warping effect of the sun's direct and reflected heat rays on the telescope (see experiments in Table No. 6). All other errors are generally of a compensating nature when good instruments are used" (page 886).

> Again: "The error shown to exist in very warm weather (see Table No. 6) cannot be detected, except by the closure of a line, and the best and most careful work may be done under seemingly good conditions without yielding satisfactory results" (page 862).

On pages 843 and 883 important conclusions are also based upon this table as to the times of day and kinds of weather in which good work can be done. Finally, page 859, the author states that his conclusion, based upon Table No. 6, as to the times of day when double lines should be run, "supersedes all theoretical reasoning, being, as it is, the result of actual observation and experiment."

The experiments in question are confined to a single day and a single instrument station. Has the author shown good judgment in using these experiments as a foundation for the great superstructure of far-reaching conclusions which he has constructed? Or, if he has additional supports for his superstructure, is he not unwise in leaving the reader in ignorance of them? Mr. Hayford.

When one examines the evidence carefully, with a view to answering the above questions, the first doubt is apt to arise in his mind as soon as he notices that all the experiments were made under one set of conditions. One of the primary conditions which must be fulfilled by a set of experiments, if the conclusions based upon them are to be thoroughly trustworthy, is that the conditions under which they are made must be varied as much as possible. In the case in hand, the direction of the line observed might have been varied; the observations might have been taken on different days; the character of the surface of the ground should have been varied, and the effect of the slope of the ground should surely have been taken into account as possibly affecting the refraction. As it is, all the readings are taken over the same line, and the only conditions which vary are the time of day, the temperature, cloudiness or brightness of the sunlight, and the azimuth of the sun.

The mean reading of Rod 5 varied during the experiments from 1529.2 mm. to 1529.9 mm., or a total of 0.7 mm. Similarly, the range of the readings on Rod 1 was 1.4 mm. The total change in the apparent difference of elevation of the two rod supports is from 287.1 mm. to 288.0 mm., or a total of 0.9 mm. All the author's conclusions are based upon these small changes. Is the internal evidence of Table No. 6 such as to make it unquestionably true that the accuracy of the observations was sufficient to warrant any conclusions drawn from such small variations. A side-light upon this question may be gained by noting the range of variation of the angle subtended on the rod by the upper and lower threads. Omitting the first values given in the table, because the instrument was moved, as stated in the text, between the first and second observations, the thread distance on Rod 5 varies from 151.6 mm. to 152.1 mm., or a range of 0.5 mm., and on Rod 1 varies from 151.8 mm. to 152.6 mm. or a range of 0.8 mm. It should be noted that the author's explanation of the changes in the mean rod readings and the apparent difference of elevation in the rod supports does not in the least account for any apparent change in the thread distances. If the eye end of the telescope curves downward during a part of the observations, as he assumes, all three threads will apparently move together on the rod, and the thread distances remain constant. The variation in thread distance which could be accounted for by a change in temperature of the reticule would be in the hundredths of a millimeter only. The range of variation in thread distances referred to, viz.: 0.5 and 0.8 mm.. must be due either to errors of observation or changes in the difference of refraction between the upper

Mr. Hayford. and lower lines of sight. The errors from either of these causes are equally likely to affect the mean readings of the rods and the apparent difference of elevation of the rod supports. It seems, therefore, that to base any far-reaching conclusions on a variation of 0.9 mm. during a set of observations, when variations of 0.5 to 0.8 mm. remain unexplained, is unwarranted. The author's conclusions may possibly be correct, but Table No. 6, without support, hardly can be taken as proof of such correctness.

It is stated that the error of the determination of the difference of height of the two rod supports in this set of experiments became zero at 8 A. M. and 3 P. M. (page 842). An examination of the table indicates then that the author considers the true difference of elevation to be 288.0 mm. There is no evidence put forward by the author to determine which of the many measured differences of elevation was the true one. What evidence is furnished that the greatest of the measured values corresponds to the truth, rather than the mean of all the measures. A dogmatic statement is made, without any effort to support it. This statement is of especial importance as the conclusions stated in various other parts of the paper, as to the time of day when good work can be done, all depend upon the correctness of this assumption that 288.0 mm. is the true difference of elevation.

The author states positively that to detect temperature errors of the class which he claims are indicated in Table No. 6 it is necessary to close each stretch of the line by making both the forward and the backward measures during the same half of the day (pages 843, 859 and 883). Even if the author's conception of the cause of such temperature errors be agreed to, and even if it be agreed that the measurements shown in Table No. 6 are absolutely accurate, the conclusion stated does not follow. Let it be agreed that in running a line northward, as indicated in Table No. 6, the eye end of the telescope curves downward on the fore sight and thus inclines the line of sight upward, and that the elevations carried northward will be too small, it is equally true that, if the direction of the running were to the southward, under the same conditions, according to the author's theory the fore sight, which would then be toward the sun, would be undisturbed, while the back sight, taken from the sun, would be made too high on the rod, and the ultimate effect would be to tend to make the line run high, just as in the previous case it was supposed to run low. If the first measurement to the northward be called the forward measurement and the second the backward measurement, the forward measurement would carry the measures too low and the backward measurement would carry them too high in the direction of the measure, which is now reversed, and the two results would agree instead of showing a divergence. In other words, by the author's theory as to the manner of behavior of the telescope, it is necessarily true that elevations car-

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ried in the computation from one bench-mark to another which is in a direction away from the sun from the first will be too low, regardless of the direction in which the measurements actually progressed, and *vice versa*. To make the backward and forward measurements on the same half day on an east and west line is to insure a better agreement of the two measures than if they are made under differing conditions. This is the reverse of the claim made by the author, when applied to such a line. The logical conclusion from his theory would be that if the forward measure is made under one set of conditions as to the azimuth of the sun and cloudiness, the backward measure should be made under conditions as different as possible in these respects if it is desired to make the temperature error apparent by producing a divergence between the two lines, as he claims, and correctly, should be done. The correct conclusion is, for example, that on a line running to the westward, if the forward measurement is made in the forenoon with the sun behind, and the measures may therefore be expected to carry the elevations too low in the direction of the progress of the measurement, the backward measurement should be made in the afternoon with the sun again behind and with the line again running low in the direction of progress.

A test of the validity of the author's conclusion that this temperature error may be as much as 15 mm. per kilometer (see middle of page 843) is available in the printed reports of the Coast and Geodetic Survey. The general custom from the beginning, on that Survey, has been for the level party to continue working throughout the day. In the various stretches of line comprised in hundreds of miles of leveling done by the forward and backward method it is necessarily true that all combinations of conditions as to the relative times of the runnings of the forward and backward line have occurred, but no divergence approaching 15 mm. per kilometer can be found in the observations.

It is interesting to note that the result from the experimental line run southward on a clear, warm day without any umbrella, stated on page 843, agrees with the theory of temperature errors stated, in connection with the leveling of the Coast and Geodetic Survey previous to 1899, earlier in this discussion. According to that theory a level line run toward the sun should always have a tendency to run too high, and, of course, this tendency would be greatly exaggerated when no umbrella is used.

The writer's opinion then in regard to Table No. 6, and the conclusions based upon it, is that the evidence of the table is too weak to support any conclusion, and that the author's theory of temperature errors must necessarily be supported by other evidence before it can be accepted; that the conclusion drawn from the table that good work cannot be done during the hottest part of the day is not valid; and, Mr. Hayford. finally, that the conclusion that the forward and backward running on any section of the line should be made on the same half day is utterly contrary to the author's own statement of the nature of the error supposed to have been manifested in the table.

During What Hours of the Day should Leveling be Done?—The author is not alone in his contention that the hours of observing should be limited to the beginning and end of the day, and that the middle and heated half should be avoided. Such a proposition is put forward in many places in the literature of leveling, both by direct statement and by the indirect statement involved in the fact that the hours of leveling were actually so limited. The question as to whether the hours of work should be so limited is important, because it is one of the principal factors in determining the speed of the leveling per month and its cost. If the hours of work are extended say from 5 to 8 hours during each day, on an average, the speed will be affected in that ratio and the cost in the inverse ratio, since the main portion of the expense of the party is a fixed amount per month. In view of this it seems that no sufficient proof of the necessity for limiting the hours of work has ever been put forward in so far as the writer is aware.

In general, less vibration of the images of the rod as seen through the telescope may be expected during the early and late hours of the day, or at least the vibration will be less violent than during the middle portion of the day. Smaller errors of reading of the rods may, therefore, be expected during the early and late hours than in the middle of the day. But such reading errors are compensating in their nature, and are of minor importance. The most troublesome errors are those of the cumulative class.

It can hardly be contended that there is less danger of errors due to large or rapidly changing refractions during the early and late parts of the day than during the middle, for it is a well-known fact that the refraction is varying most rapidly during the early and late hours, and that it is also much larger during those hours than during the middle of the day. It would seem that there is less chance of encountering errors due to refraction when observations are taken during the middle portions of the day, when refraction is nearly constant and is nearly a minimum, than during the early and late hours.

It might have been urged with considerable force that errors due to unequal temperature changes in the instrument might be expected to be smaller during the early and late hours than during the middle of the day, but, so far as the writer is aware, such an argument has never been put forward in the past, when it would have been valid. If brought forward now it will be of little weight, since it is reasonably certain that such errors can be kept within very narrow limits by proper construction of the instrument and proper methods of using

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it. Everything being considered, it would seem that the best plan of work is to continue the leveling throughout the day. Such a procedure will be very effective in increasing the speed and decreasing the cost. It will secure a much wider divergence of conditions than the plan of working only at the two ends of the day. The writer believes that it is true in leveling, as it is true in general, that the truth is to be reached by observing under all possible conditions and combining the results rather than by arbitrarily selecting one set of conditions.

The Principle of Least Squares.—The workman who does not understand his tool is apt to see more faults in it than one who has mastered it. The author condemns the principles of least squares as applied to leveling, except when used to compare the accuracy of different lines. The writer freely concedes that many absurdities have resulted from supposed applications of these principles. He believes, however, that the responsibility for these absurdities may always be traced to the users of the principles. The method of least squares is a most powerful instrument in the hands of an expert, but a dangerous plaything in other hands.

Certain palpable mistakes, in the application of least squares to the problem in hand, catch the eye at once. The formula given on page 878, $\pm r_0 = \sqrt{\Sigma r^2}$, in which r_0 is the probable error of the elevation of a point as found from the initial point, and the separate r's are in each case the probable error of the mean difference of elevation of the bench-marks at the end of a stretch. It is then stated that "This formula is applicable only when all stretches are of equal length, though it is generally used without regard to the actual weights resulting from unequal lengths." The statement is a positive contradiction of one of the fundamental principles of the theory of errors, that the probable error of the sum of several quantities is equal to the sum of the squares of the separate probable errors, regardless of the relative weight of the separate quantities. Again it is stated (page 883) that:

> "Three single lines would yield a theoretical accuracy of 1.4 times that obtained from two lines, * * * and four lines would give an accuracy of 1.7 times that from two lines."

The theoretical accuracy increases as the square root of the number of measures of single lines, and the foregoing ratios, therefore, should be $\sqrt{\frac{3}{2}}$ and $\sqrt{\frac{4}{2}}$ or 1.2 and 1.4, instead of 1.4 and 1.7 as given.

The statement that, "When a line of levels closes on itself, thus forming a polygon, the resulting error of the polygon must be distributed over the entire periphery, either in proportion to the length, or, perhaps better, in proportion to the square root of the length, from the known starting point," given on page 894, is evidently the result of a misconception of the principles under discussion.

To distribute such an error in proportion to the square root of the

Mr. Hayford. length from the known starting point would be an absurdity and would give two results which would vary widely from each other when the distribution was made first in one direction around the circuit and then the other. It is stated on page 889, that when the theory of error is applied to the comparison of groups of observations, "each group must contain the same number of observations."

In view of the foregoing quotations the condemnation of the theory of errors as applied to precise leveling (pages 889-890), and especially the condemnation of the method of least squares, as applied to the adjustment of a level net, should be given but little weight.

Probable Errors and Limits of Error.—The computed probable error of a single kilometer is a true measure of the relative magnitude of the errors belonging to the accidental or compensating class in different lines. Such comparisons are misleading, however, unless it is kept clearly in mind that the accuracy of the line of levels depends both upon the compensating and the cumulative errors in that line. The errors of the second class are usually much more serious than those of the first, in precise leveling. The probable errors on two lines being known, judgment should be suspended until the evidence as to the magnitude of the cumulative errors has been weighed. For example, the two groups of lines shown in Table No. 21 have average probable errors which do not differ greatly. An opinion of the relative accuracy of the two groups based upon this fact would be grossly at fault, however, since the average cumulative error in one of these groups is many times that in the other. The best evidence of the magnitude of the cumulative errors in any class of leveling is furnished by connections with tide gauges, large circuits of leveling of that class, or numerous connections with leveling of some other class.

Similarly, to appreciate the true significance to be attached to a limit of error, it should be noted that it is essentially a specification that the probable errors must not exceed a certain value. As such, it limits the errors of the compensating class, and does not affect the far more serious errors of the cumulative class.

Speed and Accuracy of Coast and Geodetic Survey Leveling, 1899–1900.—The probable errors of the leveling of a single kilometer, computed on the same basis as the values in Table No. 21, were, for three C. & G. S. parties in 1899 on three lines aggregating a total length of 1 300 km., or 800 miles, ± 0.86 mm., ± 0.8 mm. and ± 0.65 mm. The office computation of the leveling of 1900 has not yet been begun, and the 1900 values are, therefore, not available, but an inspection of the field computations indicates that the probable errors will be about the same as in 1899.

The foregoing values do not represent the best that the instrument and method will do, for the following reasons: Knowing that the probable error and the limit of error indicate simply the magnitude of

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the accidental or compensating errors, while the serious errors to be feared in the leveling are of the cumulative class and the compensating errors comparatively unimportant, it seemed that instructions to the observers should be to use all possible efforts to guard against cumulative errors, but that no more time or money should be expended upon the work than was necessary to keep the accidental or compensating errors within the limit indicated by a computed probable error of ± 1 mm. for a single kilometer. The limit 4 mm. $\sqrt{K}$ (in which K is the distance between adjacent bench-marks in kilometers) was chosen as being about right to insure this degree of accuracy, in so far as compensating errors are concerned. The observers were not, however, left free to do any class of work they pleased, subject only to the condition that they must keep inside of this limit. On the contrary, they were told to crowd the limit, so to speak, by lengthening the sights so as to secure increased speed. When two of the parties observed in such a cautious manner that little or no re-running under the limit stated was necessary they were promptly reminded that they were not following the spirit of the instructions, that too much caution was being used, and that the sights should be lengthened. The effect of the instructions was, therefore, virtually to make the probable error fall between ± 0.6 and ± 1.0 mm., and to require the observer to use his skill and judgment in increasing the speed of the leveling rather than in reducing the probable error. From the foregoing it will be seen that the probable error secured and the speed attained must necessarily be considered together.

The general experience of all organizations which have done much precise leveling indicates that the real accuracy of the leveling depends upon the success in eliminating the cumulative errors rather than in reducing the accidental errors. The question may be asked: Upon what is based the writer's opinion that the leveling of 1899 and 1900 is of a very high degree of accuracy, and that in it there are no large cumulative errors? Since, as indicated above, and elsewhere in this discussion, the probable error computed from the residuals on the separate sections is not considered a measure of accuracy, the writer does not feel absolutely certain of the grade of accuracy of the 1899 and 1900 leveling, and will not feel absolutely certain until such leveling has been subjected to severe tests by being involved in many circuit closures. Nevertheless, the confidence that this leveling, when subjected to such severe tests later, will not be found wanting, is based mainly upon four facts stated as follows, in increasing order of importance:

1st. A careful examination of the 1899 leveling by use of the notes as to weather, direction of sun, direction of wind and direction of line, taken by the parties during that season, shows that the temperature errors of the form discovered in the old leveling are exceedingly small, if present at all, in the new leveling.

Mr. Hayford. 2d. Three long loops of single line were run in Ohio in 1899 by this method, their circumferences being 82, 112 and 87 km., and the closing errors —4.9, +9.0 and +9.3 mm., respectively. This is a very severe test of the method, and was made still more severe by running cross-lines dividing these three loops into nine small loops.

3d. Two of the long lines run in 1899, namely, the line from Gibraltar, Mich., to Cincinnati, Ohio, and the line from Abilene, Kans., to Sioux City, Iowa (finished in 1900), are now involved in large circuits, and the results indicate the correction required by each to be exceedingly small.

4th, and most important: It must be noticed that the method of observation resembles very closely in all essential features that which has been used by the Corps of Engineers for many years, and of which the results, judged by the closing errors of large circuits, the most severe test which can be applied to any leveling, are unexcelled in accuracy up to the present time by any leveling in any country, so far as the writer is aware.

It may be noted that in the preceding paragraphs no reference has been made to the divergence between forward and backward lines as a measure of accuracy. The writer has failed to observe in the published results of leveling any relation between the magnitude of the divergence of forward and backward lines and the accuracy of such lines as indicated by the severe tests furnished by circuit closures, and he, therefore, believes that the magnitude of such divergence should be given little weight in measuring the accuracy unless the divergence is excessive. It is, perhaps, necessary to call attention especially to the fact that this statement is limited to lines which are run by the forward and backward method, in which the effect of systematic settling or rising of the rod supports is given an opportunity to manifest itself and is eliminated from the results. It is not applied to double lines in which both the components are run in the same direction. The average divergence of the forward and backward lines for the three C. & G. S. parties in 1899 were, respectively, 0.20, 0.51 and 0.08mm. per kilometer of double line. Divergences of the same magnitude as these may be found in many lines of the Corps of Engineers which have subsequently been shown by circuit closures to be unsurpassed in accuracy. It is also in point to note that one of the 1899 lines, having a divergence of 0.51 mm. per kilometer, is now involved in the circuit, Abilene—Kansas City—Sioux City—Abilene, which has closed so well as to leave no doubt of the accuracy of the line.

In stating the rapidity of observation, the number of minutes per station, speed per hour and speed per month offer convenient bases of comparison. Seven minutes per station, which is said by the author (page 895) to be the time required to walk between stations, set up the instrument and take the readings, under exceptionally good circum-

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stances with clear steady air, seems to correspond to about the average speed for C. & G. S. parties, even though they work throughout the day. On June 20th, 1900, Mr. O. W. Ferguson, with a level of the 1899 model, observed between 7.10 A. M. and noon, and 1.45 and 6.15 P. M., total, 9 hours and 20 minutes, and during that time occupied 111 stations, or an average of 5.0 minutes per station. The length of sight on this day varied from a little less than 40 to about 80 m. On September 26th, 1900, the party under Mr. W. H. Burger, using a level of the 1900 model, was engaged in running a line over very rough ground, on which it was necessary to take very short sights. The period of observation was from 7.30 A. M. to noon and from 1.40 to 5 P. M. The total number of stations during the working period of 7 hours and 50 minutes was 102, making the average time per station 4.6 minutes.

The writer does not know that these are the best examples that could be given. A more careful examination of the record may show still more rapid work. These are especially interesting as indicating how rapidly the instruments may be manipulated and the observations taken, in the very simple method now in use, and will probably bear comparison with work done with the ordinary Y-level.

A speed of one mile per hour is not at all unusual, and the record shows many days in the season when a speed of $1\frac{1}{4}$ miles, equal to 2 km., per hour has been kept up for several hours, and even throughout the day. For example, a party in charge of Mr. B. E. Tilton, ran 16.6 km., 10.3 miles, of single line on July 14th, 1899, during a working period of 7.4 hours, or at an average rate of 1.4 miles per hour. The length of sight on this day varied from 80 to 110 m. with an average of about 100 m. The best single mile of leveling which has yet come under the writer's notice was run in 34 minutes by this same party.

The speed, in terms of completed miles of leveling per month—and this is one of the important factors in fixing the average cost of leveling per mile—was as follows for the three parties operating in 1899: In Colorado and Wyoming 214 miles were completed in 5.3 months, or at the rate of 40 miles per month; in Ohio 285 miles were completed in 5.8 months, or an average of 50 miles per month; and in Kansas and Nebraska 334 miles were completed in 5.3 months, or an average of 63 miles per month. The average for the three parties is 51 miles per month. The period of work given in each case is that embraced between the first day on which observations were taken and the last. These figures make the rate of progress in completed miles for each day that the party was in the field, making no deductions for Sundays, holidays, days lost on account of rain or other causes, 1.3, 1.6, and 2.1, respectively, or an average for the three parties of 1.7. A completed mile of leveling necessarily means at least 2 miles of single line, and, upon an average, represents a little more than this, on account of re-running of sections on which the discrepancy fell slightly outside

Mr. Hayford. the limit 4 mm. $\sqrt{K}$. Hence, the foregoing values indicate that the number of miles of single line per day, making no deduction for lost time, was about 3.4, and, assuming that loss of time on account of Sundays, bad weather, etc., was 25%, this means that the rate per actual working day was, upon an average, about 4.5, even though the first runnings of sections which had to be re-run are not counted. The average rate of progress for 1900 is not yet known, as two of the parties are still in the field. The present indications are that it will exceed the average speed of 1899 by 10 to 20 per cent.

Cost.—The actual cost to the Government, of the leveling done in 1899, is as follows, in round numbers: For the party in Colorado and Wyoming, \$17 per mile = \$10 per kilometer; for the party in Ohio, \$14 per mile = \$9 per kilometer; for the party in Nebraska and Kansas, \$11 per mile = \$7 per kilometer. The average of the three parties for the whole season is \$13.55 per mile or \$8.40 per kilometer. These figures represent the actual cost of the leveling, including the establishment of the bench-marks, with the exception of the first cost of instruments and the cost of stationery supplied to the parties. It includes all transportation to and from the field, paid by the Government, the cost of inspection of the parties, and all wages and salaries, including chief of party and recorder. The salary of each member of the permanent force is charged to the leveling for the whole period during which he was engaged upon work incidental to the leveling. It includes the time spent in traveling to and from the field, and, in one case, the time spent in preparing for the field. The Government pays its permanent employees for twelve months' work per year and actually secures, on an average, only eleven months, the annual leave granted being one month per year. To take account of this fact, one-eleventh has been added to the salary actually paid each officer during the time he was connected with the leveling work. The present indications are that the average cost per mile, of the leveling in 1900, will be considerably less than it was in 1899. If the salaries of members of the permanent force, which are included in the foregoing cost, be deducted, and this is not unusual in computing the cost of leveling, the average cost per mile for 1899 will be found to be \$9.33; and per kilometer \$5.79. The field expenses per month for each of these parties were about the same. The principal factors which vary are the speed per month and the salary of the observer. The conditions under which the work was done, for these three localities, also differed considerably. The three values of the cost are, therefore, given, not as a comparison of the parties, but as an indication of the extent to which the cost per mile may vary, though the instruments and methods are identical.

The cost of the leveling as given may be compared with that given in the paper (page 897), namely, \$16 per mile, or \$10 per kilometer,

Mr. Hayford.

not including the establishment of bench-marks; or, including the establishment of bench marks, $15 per kilometer or $24 per mile. It may also be noted that this estimate by the author does not include the traveling expenses to and from the field. A comparison may also be made with the values given in the paper* by H. M. Wilson, M. Am. Soc. C. E., namely, the cost of from $19 to $32 per mile for leveling by the Engineer Corps. Also on the same page it is indicated that 265 miles of C. & G. S. leveling cost $3 900, or an average of $14.72 per mile (not $10.94 as there printed). This estimate of the cost of the old C. & G. S. leveling, namely, $15 per mile, is probably considerably less than the average cost of that leveling, salaries of observers being included. Also, on page 416 of the same volume, it is indicated that 1 000 miles of the leveling by the Engineers along the Missouri River cost about $20 per completed mile. Throughout the preceding paragraphs the cost is given for a completed mile of leveling, comprising at least two runnings, and should not be confounded with the cost per mile of single line.

In each of the comparisons suggested above if the details are examined it will surely be found that the comparison is biased against rather than on the side of the new C. & G. S. levels. It will be found that in general some of the items involved in the total cost to the Government have been omitted, as, for example, transportation to and from the field, or salaries of observers, or other items.

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* *Transactions*, Am. Soc. C. E., Vol. xxxix, p. 377.

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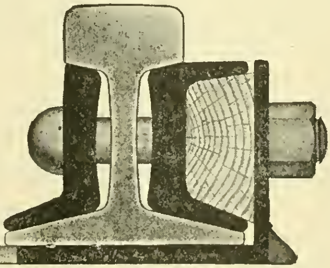

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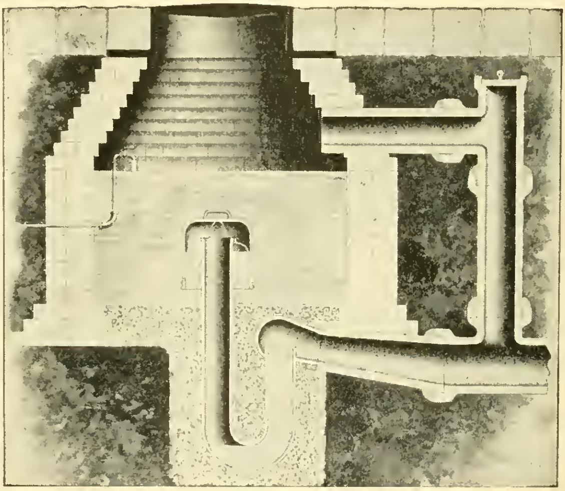

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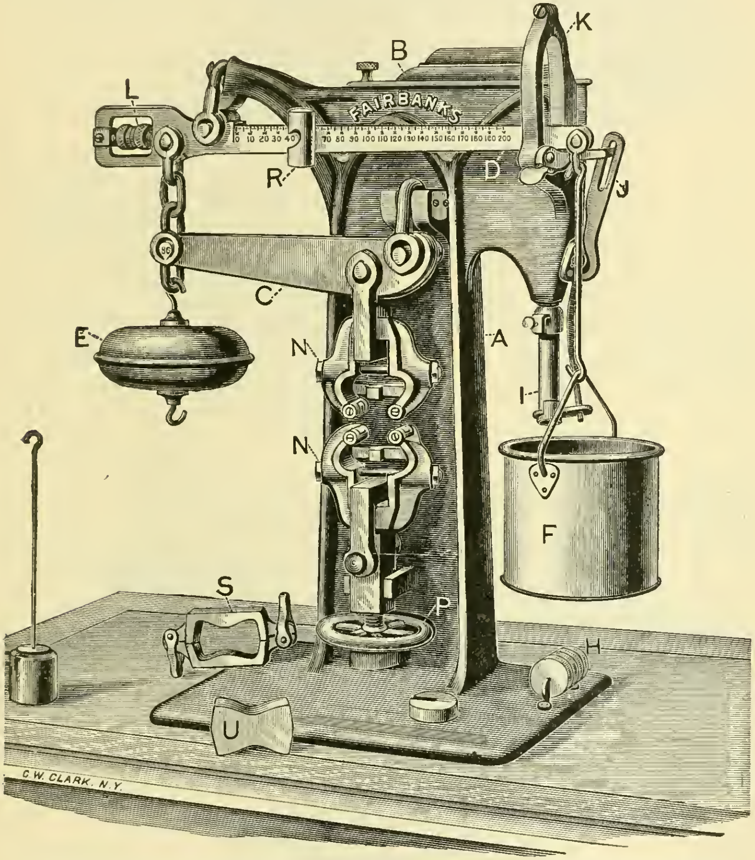

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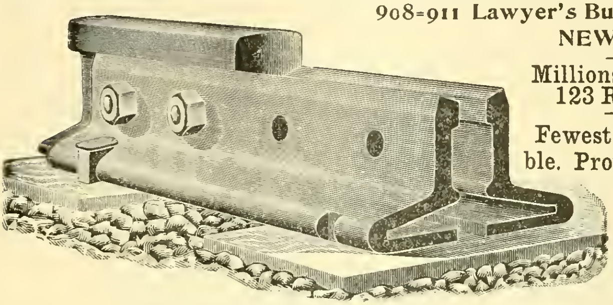

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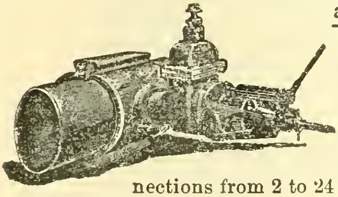

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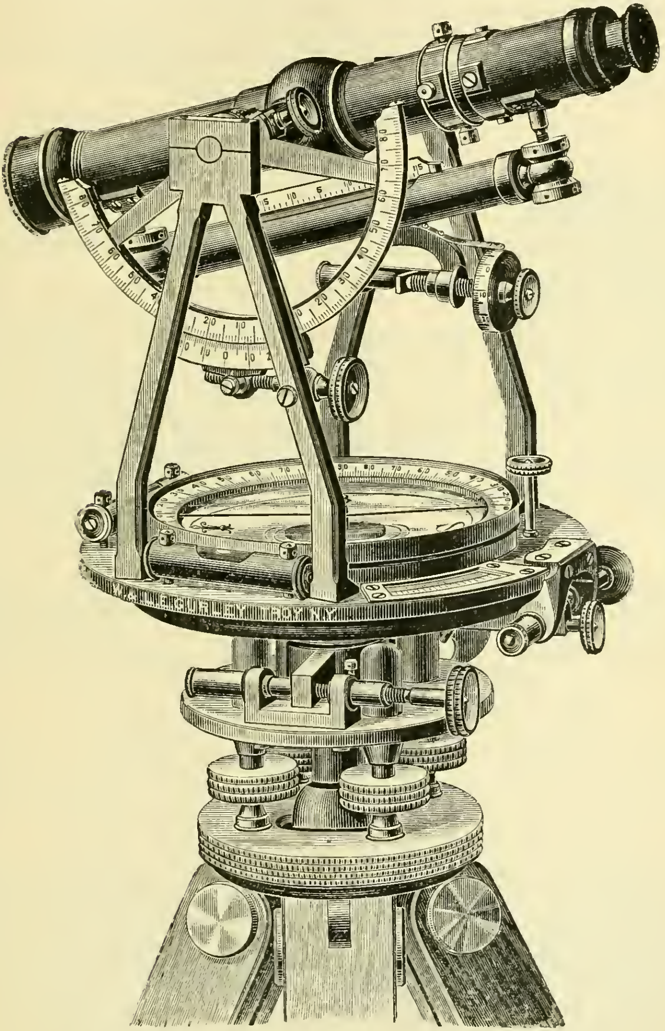
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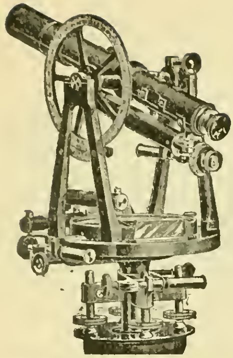

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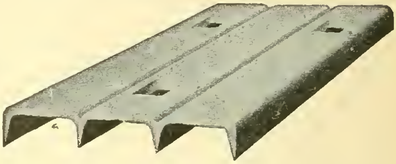

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AMERICAN SOCIETY

OF

CIVIL ENGINEERS

December, 1900

PROCEEDINGS = VOL. XXVI—No. 10

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Vol. XXVI. DECEMBER, 1900. No. 10.

PROCEEDINGS

OF THE

AMERICAN SOCIETY OF CIVIL ENGINEERS.

Edited by the Secretary, under the direction of the Committee on Publications.

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The prices of publications are as follows: *Proceedings*. $6 per annum; *Transactions*, $10 per annum. Postage will be added when *Proceedings* are sent to foreign countries.

American Society of Civil Engineers.

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Special Committees.

On Analysis of Iron and Steel:—Sub-Committee of the American Society of Civil Engineers (of the International Committee on Standards for the Analysis of Iron and Steel, of which Prof. J. W. Langley is Chairman)—Charles B. Dudley, William Metcalf, Thomas Rodd.

On Units of Measurement:—George M. Bond, William M. Black, R. E. McMath, Charles B. Dudley, Alexander C. Humphreys.

On the Proper Manipulation of Tests of Cement:—George F. Swain, Alfred Noble George S. Webster, W. B. W. Howe, Louis C. Sabin, H. W. York.

◆

The House of the Society is open every day, except Sunday, from 9 a.m. to 10 p.m.

House of the Society—220 West Fifty-seventh Street, New York.

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Vol. XXVI. DECEMBER, 1900. No. 10.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PROCEEDINGS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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MINUTES OF MEETINGS.

OF THE SOCIETY.

December 5th, 1900.—The meeting was called to order at 8.45 P. M.; J. James R. Croes, M. Am. Soc. C. E., in the chair; Charles Warren Hunt, Secretary; and present, also, 78 members and 17 visitors.

The minutes of the meetings of November 7th and 21st were approved as printed in *Proceedings* for November, 1900.

A paper by Ewald Schmitt, Assoc. M. Am. Soc. C. E., entitled "A Direct Method of Spacing Rivets and Finding the Position, etc., of Stiffeners in Plate Girders," was presented by the Secretary, who also presented a written discussion by J. W. Schaub, M. Am. Soc. C.E.

The subject was discussed orally by Messrs. George Devin, H. A.

LaChicotte, Bernt Berger, O. F. Nichols, F. D. Rhodes and F. W. Skinner.

Ballots were canvassed, and the following candidates were declared elected:

As MEMBERS:

FREDERICK HAYNES NEWELL, Washington, D. C.
ALLEN NEWHALL SPOONER, New York City.

As ASSOCIATE MEMBERS:

ROBERT CRARY BARNETT, Kansas City, Mo.
EDWIN GUY HELM, East St. Louis, Ill.
ORVAL OMAR MCREYNOLDS, Pueblo, Colo.
JUSTIN OAKLEY REYNOLDS, New York City,

The Secretary announced that the following candidates were elected by the Board of Direction, December 4th, 1900:

As ASSOCIATE:

WALLACE KING, Jr., New York City.

As JUNIORS:

PAUL ALEXANDER BLACKWELL, St. Louis, Mo.
HENRY DE BRETTON FORBES, Durango, Mexico.
HENRY GARFIELD PERRING, Little Rock, Ark.
LOUIS DOWNER TRACY, Allegheny, Pa.
WILLIAM ELISHA PRUETT, Kansas City, Mo.
ALEXANDER THOMSON, Jr., New York City.

The Secretary announced that at the meeting of the Board of Direction, December 4th, 1900, the ballot on the reconsideration of EDGAR DAY KNAP was canvassed, and that Mr. Knap was declared elected as an Associate Member.

The Secretary announced the death of HENRY WADSWORTH REED, elected Member January 6th, 1886; died October 26th, 1900.

The Secretary announced the acceptance of the following resignations:

JARED AUGUSTINE SMITH, elected Member May 2d, 1883.
PORTER DWIGHT FORD, elected Member March 5th, 1890.

Adjourned.

December 19th, 1900.—The meeting was called to order at 8.45 P. M.; Vice-President Rudolph Hering in the chair; Charles Warren Hunt, Secretary, and present, also, 79 members and 14 visitors.

A paper by J. I. Boggs, Assoc. M. Am. Soc. C. E., entitled "Some Peculiar Railroad Bridge Accidents," was presented by the Secretary.

The subject was discussed by Joseph Mayer, M. Am. Soc. C. E.

The Secretary announced the death of William Starling; elected Member September 7th, 1887; died December 11th, 1900.

Adjourned.

OF THE BOARD OF DIRECTION.

(Abstract.)

December 4th, 1900.—8.15 P. M.—Vice-President Noble in the chair; Charles Warren Hunt, Secretary; and present, also, Messrs. Bensel, Buchholz, Knap, Morison, O'Rourke, Schneider, Seaman, Ricketts, Turner and Whinery.

The Chairman was authorized to appoint a Committee to take charge of the arrangements for the Annual Meeting.

The following resignations were presented and accepted:

Jared A. Smith, M. Am. Soc. C. E.; Porter D. Ford, M. Am. Soc. C. E.

The reconsideration ballot in the case of Edgar Day Knap was canvassed by the Board, and Mr. Knap was declared elected an Associate Member.

Applications were considered and other routine business transacted.

One Candidate for Associate and six for Junior were elected.

Adjourned.

ANNOUNCEMENTS.

In accordance with the resolution of the Board of Direction, the House of the Society is open every day, except Sunday, from 9 A. M. to 10 P. M.

MEETINGS.

Wednesday, January 2d, 1901.—8.30 P. M.—A regular business meeting will be held. Ballots for membership will be canvassed, and a paper, entitled "The Kinzua Viaduct of the Erie Railroad Company," by C. R. Grimm, M. Am. Soc. C. E., will be presented for discussion.

This paper is printed in the November number of *Proceedings.*

Wednesday, February 6th, 1901.—8.30 P. M.—A regular business meeting will be held. Ballots for membership will be canvassed, and a paper, entitled "The Adjustment of a Transit Survey as Compared with that of a Compass Survey," by Charles L. Crandall, M. Am. Soc. C. E., will be presented for discussion.

This paper is printed in this number of *Proceedings.*

Wednesday, February 20th, 1901.—8.30 P. M.—A regular meeting will be held, at which a paper, entitled "The Construction of Gravity Sand Filters at Nyack, N. Y.," by G. N. Houston, Assoc. M. Am. Soc. C. E., will be presented.

This paper is printed in this number of *Proceedings.*

ANNUAL MEETING.

The forty-eighth Annual Meeting will be held at the Society House, January 16th and 17th, 1901. The Business Meeting will be called to order at 10 o'clock on Wednesday morning. The annual reports will be read, officers for the ensuing year elected, members of the Nominating Committee appointed, amendment to the Constitution considered, and other business transacted.

Messrs. Joseph O. Osgood, R. S. Buck, Albert Carr and Charles Warren Hunt have been appointed a Committee of Arrangements, and are preparing a programme of the social features and excursions.

PROPOSED AMENDMENT TO THE CONSTITUTION.

The following proposed amendment to the Constitution has been received by the Secretary, and has been sent to the Corporate Members of the Society, in accordance with the provisions of Section 2 of Article IX of said Constitution:

"Amend Section 5 of Article II by adding the following:

"*The Board of Direction may transfer any Junior elected prior to March 4th, 1891, to the grade of Associate.*"

This amendment is proposed by George S. Morison, S. Whinery, Joseph M. Knap, John Bogart and C. C. Schneider.

NOMINATING COMMITTEE.

Heretofore, seven members of the Nominating Committee, one from each of the Geographical Districts, have been elected annually at the Annual Convention.

The amendment to the Constitution adopted October 3d, 1900, provides that this election shall take place at the Annual Meeting.

The usual blank request for suggestions as to representatives of each district has been mailed to Corporate Members, and the result of the suggestions made will be reported to the meeting.

ANNUAL CONVENTION OF 1901.

The Thirty-third Annual Convention of the Society will be held at Niagara Falls, N. Y., on Tuesday, Wednesday, Thursday and Friday, June 25th, 26th, 27th and 28th, 1901.

MONTHLY LIST OF RECENT ENGINEERING ARTICLES OF INTEREST.

(November 14th to December 12th, 1900.)

NOTE.—*This list is published for the purpose of placing before the members of the Society the titles of current engineering articles, which can be referred to in any available engineering library, or can be procured by addressing the publication directly, the address and price being given wherever possible.*

LIST OF PUBLICATIONS.

In the subjoined list of articles references are given by the number prefixed to each journal in this list.

(1) *Journal*, Assoc. Eng. Soc., 257 South Fourth St., Philadelphia, Pa., 30c.
(2) *Proceedings*, Eng. Club of Phila., 1122 Girard St., Philadelphia, Pa.
(3) *Journal*, Franklin Inst., Philadelphia, Pa., 50c.
(4) *Journal*, Western Soc. of Eng., Monadnock Block, Chicago, Ill.
(5) *Transactions*, Can. Soc. C. E., Montreal, Que., Can.
(6) *School of Mines Quarterly*, Columbia Univ., New York City, 50c.
(7) *Technology Quarterly*, Mass. Inst. Tech., Boston, Mass., 75c.
(8) *Stevens Institute Indicator*, Stevens Institute, Hoboken, N. J., 50c.
(9) *Engineering Magazine*, New York City, 30c.
(10) *Cassier's Magazine*, New York City, 25c.
(11) *Engineering* (London), W. H. Wiley, New York City, 35c.
(12) *The Engineer* (London), International News Co., New York City, 35c.
(13) *Engineering News*, New York City, 15c.
(14) *The Engineering Record*, New York City, 12c.
(15) *Railroad Gazette*, New York City, 10c.
(16) *Engineering and Mining Journal*, New York City, 15c.
(17) *Street Railway Journal*, New York City, 35c.
(18) *Railway and Engineering Review*, Chicago, Ill.
(19 *Scientific American Supplement*, New York City, 10c.
(20) *Iron Age*, New York City, 10c.
(21) *Railway Engineer*, London, England.
(22) *Iron and Coal Trades Review*, London, England.
(23) *Bulletin*, American Iron and Steel Assoc., Philadelphia, Pa.
(24) *American Gaslight Journal*, New York City, 10c.
(25) *American Engineer*, New York City, 20c.
(26) *Electrical Review*, London, England.
(27) *Electrical World and Electrical Engineer*, New York City, 10c.
(28) *Journal*, New England Water-Work Assoc., Boston, 75c.
(29) *Journal*, Society of Arts, London, England.
(30) *Annales des Travaux Publics de Belgique*, Brussels, Belgium.
(31) *Annales de l' Assoc. des Ing. Sortis des Ecôle Spéciales de Gand*, Brussels, Belgium.
(32) *Memoirs et Compt Rendu des Travaux*, Soc. Ing. Civ. de France, Paris, France.
(33) *Le Génie Civil*, Paris, France.
(34) *Portefeuille Economique des Machines*, Paris, France.
(35) *Nouvelles Annales de la Construction*, Paris, France.
(36) *La Revue Technique*, Paris, France.
(37) *Revue de Mecanique*, Paris, France.
(38) *Revue Générale des Chemins de Fer et des Tramways*, Paris, France.
(39) *Railway Master Mechanic*, Chicago, Ill.
(40) *Railway Age*, Chicago, Ill., 10c.
(41) *Modern Machinery*, Chicago, Ill., 10c.
(42) *Transactions*, Am. Inst. Elec. Eng., New York City, 50c.
(43) *Annales des Ponts et Chaussées*, Paris, France.
(44) *Journal*, Military Service Institution, Governor's Island, New York Harbor, 75c.
(45) *Mines and Minerals*, Scranton, Pa., 20c.
(46) *Scientific American*, New York City, 10c.
(47) *Mechanical Engineer*, Manchester, England.
(48) *Zeitschrift des Vereines Deutscher Ingenieure*, Berlin, Germany.
(49) *Zeitschrift für Bauwesen*, Berlin, Germany.
(50) *Stahl und Eisen*, Duesseldorf, Germany.
(51) *Deutsche Bauzeitung*, Berlin, Germany.
(52) *Rigasche Industrie-Zeitung*, Riga, Russia.
(53) *Zeitschrift des oesterreichischen Ingenieur und Architekten Vereines*, Vienna, Austria.
(54) *Den Tekniske Forenings Tidsskrift*, Copenhagen, Denmark.
(55) *Ingeniören*, Copenhagen, Denmark.
(56) *Teknisk Tidskrift*, Stockholm, Sweden.
(57) *Teknisk Ugeblad*, Christiania, Norway.
(58) *Proceedings*, Eng. Soc. W. Pa., 410 Penn Ave., Pittsburg, Pa., 50c.
(59) *Transactions*, Mining Institute of Scotland, London and Newcastle-upon-Tyne.
(61) *Proceedings*, Western Railway Club, 225 Dearborn St., Chicago, Ill., 25c.
(62) *American Manufacturer and Iron World*, 59 Ninth St., Pittsburg, Pa.
(63) *Minutes of Proceedings*, Inst. C. E., London, England.

NOTE.—There are no references made in this month's list to German and Swedish periodicals.

Bridge.

A Concrete Arch Railroad Bridge.* (15) Nov. 16.
The Strength of End Joints in Wooden Trusses.* F. E. Kidder. (14) Nov. 17.
The Willis Avenue Bridge, New York.* (14) Nov. 17.
A Footway Suspension Bridge with Three Towers, at Easton, Pa.* H. G. Tyrrell. (13) Nov. 22.
The Grasshopper Creek Viaduct.* (14) Nov. 24.
The Kinzua Viaduct.* (15) Nov. 30.
Rebuilding Niagara's Cantilever.* O. E. Dunlap. (41) Dec. 1.
The American Bridge Company's New Specifications. (14) Dec. 1.
The New Kinzua Viaduct.* (14) Dec. 1.
The Green and Goat Islands Concrete-Steel Bridges at Niagara Falls, N. Y.* (13) Dec. 6.
Design and Construction of Steel Bridge Work, with Particulars of a Recent Example in Queensland.* Clements Frederick Vivian Jackson, Assoc. M. Inst. C. E. (63) Pt. 4.

Electrical.

The Relations between Electricity and Engineering.* Sir William Henry Preece, Past-President, Inst. C. E. (63) Pt. 4.
The Paris Exposition of 1900. Carl Hering. (42) Oct.
Electro-Chemistry. (26) Serial beginning Oct. 19, ending Nov. 16.
The E. M. F. of Alternators on Open Circuit. C. C. Hawkins. (26) Serial beginning Oct. 26, ending Nov. 30.
A Comparison of English and American Practice in Cable Manufacture. J. Wright. (26) Nov. 9.
Electro-Chemistry at the Paris Exhibition. H. Borns. (11) Nov. 9.
Electric Tramways in Sydney, N. S. W.* Arthur C. F. Webb. (26) Serial beginning Nov. 9, ending Nov. 16.
The Inductance of Concentric Cables.* W. H. Everett. (26) Nov. 9.
Combined Engine and Dynamo.* (12) Nov. 9.
Cutting Structural Iron by means of the Electric Arc. J. R. Carvath. (26) Nov. 9.
Electrical Plant at the Sneyd Colliery.* (26) Nov. 9.
The Alternating Current Arc.* C. Wiler. (27) Serial beginning Nov. 10, ending Nov. 17.
General Electric Company's Foundry.* C. S. Prince. (62) Nov. 15.
The Electric Equipment of the Sneyd Colliery, Burslem.* (22) Nov. 16.
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Wireless Telegraphy with Repeaters. E. Guarini and Lieut. Poncelet. (26) Nov. 16.
Lighting the Monumental Gate of the Paris Exposition.* (27) Nov. 17.
New Legislation Affecting the Use and Misuse of Electricity. (27) Nov. 17.
Some Data as to Central Station Costs. (24) Nov. 26. (27) Nov. 17.
The Development of the Magneto-Telephone Signal.* N. H. Holland. (27) Nov. 17.
The Electric Conduit Railway—Its Development and Construction.* F. G. Cudworth. (17) Nov. 17.
The Telegraph System of Siberia. H. L. Geissel. (27) Nov. 17.
Interior Wiring. G. C. Allingham. (24) Nov. 19.
Electricity at Ardross Castle.* (26) Nov. 23.
The Possibilities of Electrical Smoke Deposition. J. Wright. (26) Nov. 23.
Electric Power on the Comstock Lode.* Wynn Meredith and Wyatt H. Allen. (27) Nov. 24.
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Electric Traction Equipment of the Manhattan Elevated—New York City. (15) Nov. 30.
Relative Advantages of Direct Current and Three-Phase Distribution of Small Installations. Hardman A. Earle, M. I. E. E. (26) Nov. 30.
Telegraphs and Telephones at the Paris Exhibition. J. Gavey, M. Inst. C. E. (26) Nov. 30.
Central-Station Practice in England.* Frank C. Perkins. (9) Dec.
Electric Locomotives. H. K. Myers. (45) Dec.
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A Magneto-Electric Telegraph System.* (27) Dec. 1.
Latest Electric Train on the Manhattan Elevated.* (27) Dec. 1.
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Perfectionnements Récents dans la Galvanisation par l'Électricité.* (36) Nov. 25.

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* Illustrated.

Marine.

A Short Description of the Naval Section of the Nicolaieff Dockyard.* William Gallon Hunter, Assoc. M. Inst. C. E. (63) Pt. 4.
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The New Battleships.* (46) Nov. 17.
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Performance of the Russian Cruiser *Variag*. Charles H. Cramp. (20) Nov. 29.
Russian First-Class Battleships—*Borodino* Class.* (12) Nov. 30.
The New Armored Cruisers of the *California* and *Maryland* Types.* (46) Dec. 1.

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Some Existing Gas-Driven Power Plants.* Philip Dawson. (11) Serial beginning Sept. 7, ending Nov. 23.
Pumping by Compressed Air.* Edward A. Rix. (1) Oct.
Condensation in Steam Cylinders.* Bryan Dunkin. (11) Serial beginning Oct. 26, ending Nov. 25.
Transmission of Gas and Air Through Pipes and the Transmission of Power by Compressed air.* Frederick W. Gordon. (2) Nov.
Gas Engines and their Fuel: Facts about the New Prime Power Mover read at International Gas Congress, Paris. Aime Witz. (62) Nov. 15.
The Investigation of Gas Processes. A. C. Humphreys, M. Am. Soc. C. E. (13) Nov. 15.
Drop-Forging Machines.* (11) Nov. 16.
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Stone-Dressing Machine.* (11) Nov. 16.
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The Bethlehem Patent Treatment for High-Speed Steel-Cutting Tools. (47) Nov. 17.
The De Laval Patent Steam Turbine.* (47) Nov. 17.
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The "Underfeed" Stoker.* (22) Nov. 23.
Illuminating Gas from Sewage Sludge. (24) Nov. 26.
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Machinery in Agriculture.* George Ethelbert Walsh. (10) Dec.
Motive Power from High-Furnace Gases.* Bryan Donkin. (9) Dec.
Pulverized Fuel.* (25) Dec.
The Development of the Gas Engine. Robert S. Ball, Jr. (10) Dec.
The Steam Automobile.* J. A. Kingman. (10) Dec.
The Use of Blast Furnace Gases in Gas Engines. Prof. Joseph W. Richards. (3) Dec.
The Welsbach Light. (3) Dec.
Liquid Air Automobile.* (46) Dec. 1.
Liquid Fuel. E. L. Orde. (47) Dec. 1.
Multi-Cylinder Gas Engines. C. P. Malcolm. (41) Dec. 1.
The Relative Efficiencies of Triple and Quadruple Expansion Engines.* A. L. Mellanby. (47) Dec. 1.
Why Compounding Gas Engines Failed. H. J. Podlesak. (41) Dec. 1.
Difficulties in the Construction of a Concrete Gasholder Tank.* F. G. Cockey. (24) Dec. 3.
Building Mighty Engines: Westinghouse Machine Company's Work Aggregates 150 000 Horse Power.* (62) Dec. 6.
Compressed Air Motors. H. D. Cooke. (62) Dec. 6.
Reminiscences of Early High-Speed Steam Engineering.* Charles T. Porter, Hon. M. Am. Soc. M. E. (13) Dec. 6.
An American Central-Valve Steam Engine.* E. T. Adams, M. Am. Soc. M. E. (13) Dec. 6.
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OF THE

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OF

CIVIL ENGINEERS.

(INSTITUTED 1852.)

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

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Note.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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THE ADJUSTMENT OF A TRANSIT SURVEY AS COMPARED WITH THAT OF A COMPASS SURVEY.

By Charles L. Crandall, M. Am. Soc. C. E.

To be Presented February 6th, 1901.

Compass Survey.

The method of adjustment of the latitudes and departures of a compass survey by Dr. Bowditch's rule, distributing the error in latitude proportionately to the lengths of the sides, and similarly for the departures, is familiar to all civil engineers and surveyors.

The fundamental principles upon which it is based, and the assumption which was made to render the rule simple, are not so generally known.

The main steps are readily traced. The latitude equation is

$$L = l \cos. B \dots\dots\dots\dots\dots\dots\dots\dots (1)$$

where L = latitude, l = length of side, and B = bearing.

If this equation be differentiated first with respect to l and then with respect to B, it will give the effect upon the latitude of a small change in distance, or of a small change in bearing.

Note.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers with discussion in full will be published in *Transactions*.

Thus, $d\,L' = d\,l \cos.\ B.$

$d\,L'' = -\,l \sin.\ B\,d\,B.$

The uncertainty, or error as it is usually called, in latitude, due to the combined effect of an uncertainty in distance and also in bearing, is equal to the square root of the sum of the squares of the effects due to each separately, where positive and negative errors are equally probable. Thus, if $r_l =$ the error in distance, replacing $d\,l$, $r_B =$ the error in bearing, replacing $d\,B$, the corresponding error in latitude squared,

$$r^2_L = r^2_l \cos.^2 B + l^2\, r^2_B \sin.^2 B \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

For the departure,

$$D = l \sin.\ B \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Differentiating and substituting as above,

$$r^2_D = r^2_l \sin.^2 B + l^2\, r^2_B \cos.^2 B \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Dr. Bowditch assumed,

$$r^2_l = r^2_B\, l^2 = l \times \text{constant} = l\,C \ldots\ldots\ldots\ldots\ldots (5)$$

which reduces equations (2) and (4) to

$$r^2_L = r^2_D = l\,C \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

i. e., the squares of the uncertainties, or probable errors, in latitude and in departure, are proportional to the lengths of the sides.

In the Method of Least Squares it is shown that the most probable corrections will be those the sum of whose squares is a minimum after each correction has been divided by its probable error; *i. e.*, if the corrections in latitude for the different sides be denoted by v_1, v_2, $v_3 \ldots$, we shall have

$$\frac{v_1^2}{l_1} + \frac{v_2^2}{l_2} + \frac{v_3^2}{l_3} + \ldots = \text{minimum}.$$

Differentiating,

$$\frac{v_1}{l_1}\,d\,v_1 + \frac{v_2}{l_2}\,d\,v_2 + \frac{v_3}{l_3}\,d\,v_3 + \ldots = 0 \ldots\ldots\ldots\ldots (7)$$

Since the sum of the corrections must equal the total error in latitude with its sign changed, a constant,

$$v_1 + v_2 + v_3 + \ldots = k.$$

Differentiating,

$$d\,v_1 + d\,v_2 + d\,v_3 + \ldots = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Comparing (7) and (8), and remembering that each must hold whatever the number of sides, or v's, we have

$$\frac{v_1}{l_1} = \frac{v_2}{l_2} = \frac{v_3}{l_3} = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

i. e., the corrections in latitude are proportional to the lengths of the sides, according to the old rule.

The same demonstration will hold for the corrections in departure.

The interesting point, in this connection, is the assumption—Equation (5)—made by Dr. Bowditch that the probable error in chaining equals the probable error in bearing (in π-measure) multiplied by the distance, and increases as the square root of the distance.

The inaccuracy of chaining is usually spoken of as proportional to the distance, but in comparing the different lines of a survey measured with the same chain, the square root of the distance as assumed above is more nearly correct. Assuming an uncertainty which would amount to 1 ft. in 500, which is not unreasonable for compass work, we would have from (5)

$$r_{500} = 1 = \sqrt{500\, C} \quad ; \text{ or } C = 0.0447,$$

from which $r_l = 0.0447 \sqrt{l}$; r_B (in minutes) $= \dfrac{0.0447}{\sin. 1' \sqrt{l}}$

Substituting for different distances gives the results shown in Table No. 1.

TABLE No. 1.

Distance, in feet.	Uncertainty in chaining, in feet.	Uncertainty in bearing.
10	0.14	0° 48′
50	0.32	0 21
100	0.45	0 15
500	1.00	0 07
1 000	1.41	0 05
2 000	2.00	0 03

An examination of Table No. 1 will show that the assumption is fairly reasonable, although it gives too great weight to the bearings of long lines, and perhaps too small to those of very short lines.

The method is thus satisfactory as to accuracy and simplicity when applied to the adjustment of a compass survey.

TRANSIT SURVEY.

In a transit survey proper, no bearings are taken except as a check, but the horizontal angles between the lines are measured. In computing latitudes and departures, or co-ordinates, a meridian is assumed, and the bearings or azimuths are computed from the horizontal angles. The bearing of the first line from the meridian involves only one angle; that of the second, two angles; etc., one-half way around the figure; the bearings for the other half being more accurately computed by working backward from the meridian.

Thus, with the following notes:

Sta. 1. Deflection, $M_1 = 92° \; 0' \; R.$ Distance, $l_1 = 236$ ft.
2. $M_2 = 46 \;\; 0 \;\; R.$ $l_2 = 244$
3. $M_3 = 82 \;\; 0 \;\; R.$ $l_3 = 324$
4. $M_4 = 51 \;\; 57 \;\; R.$ $l_4 = 183$
5. $M_5 = 88 \;\; 0 \;\; R.$ $l_5 = 437$

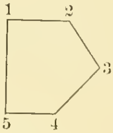

Fig. 1.

Assume 5 — 1 as a meridian (Fig. 1).

Bearing, $B_1 = 180 - M_1$ $= \text{S.}88° \; 00' \; \text{E.}$
$B_2 = B_1 - M_2 = 180 - (M_1 + M_2)$ $= \text{S.}42 \;\; 00 \;\; \text{E.}$
$B_3 = M_3 - B_2 = M_1 + M_2 + M_3 - 180°$ $= \text{S.}40 \;\; 00 \;\; \text{W.}$
$= 180° - (M_5 + M_4)$ $= \text{S.}40 \;\; 03 \;\; \text{W.}$
$B_4 = M_4$ $= \text{N.}88 \;\; 00 \;\; \text{W.}$

The discrepancy in angle work is thus thrown into the difference between the bearings of the two lines meeting at 3, and would not be properly distributed by the compass method of adjustment. If the deflections were first adjusted to close the figure, the compass survey method would allow the inaccuracy of the chaining to change the adjusted angles without giving proper weight to the accuracy of angle measurement.

There is thus no reason to assume, as appears to have been almost universally done, that because the Dr. Bowditch rule gives a close adjustment for a compass survey, it will do so for a transit survey.

Theoretically, there are three equations which must be satisfied in adjusting the observed quantities:

(*a*) The sum of the interior angles must equal twice as many right angles as the figure has sides, less four.
(*b*) The algebraic sum of the latitudes must equal zero.
(*c*) The algebraic sum of the departures must equal zero.

The Method of Least Squares requires that the corrections must be such as to satisfy the above conditions, and make the sum of their squares, each square being divided by the square of its probable error, a minimum. Since each bearing must be expressed in terms of the measured angles, and the number of measured angles in each varies from one to one-half the number of sides, the labor involved is too great for the adjustment of an ordinary transit survey.

In ordinary work the probable error of an angle need not exceed 1 minute, if care is taken in setting over the points and in plumbing the flag poles, using tacks on the stakes for all lines of less than 300 ft., swinging without delay from the back sight to the front sight, and lining in a "range" point to swing from for all lines of less than 50 ft. With these precautions, the probable error need not increase with the shortness of the line, as with the compass.

On very rough ground, or in going through brush, where the flag pole is partly hidden, it may be difficult to keep the probable error below 2 minutes; while, for careful work, the probable error can be readily kept within ½ minute.

For good work the length of sight should be limited to about 1 200 ft.

Ordinarily, it will be more difficult to measure distances to 1:500 than angles to minutes, while an accuracy of 1 : 1 000 is seldom reached except on level ground or for city work.

The accuracy of angle work is thus considerably greater than that of chaining, 1 minute in angle giving 0.15 ft. in 500 as compared with 1 ft. in chaining; or, 0.5 minute, 0.15 ft. in 1 000, as compared with the 1 ft. due to the more accurate chaining.

On this account, it will be admissible to first adjust the angles to close the figure, then compute the bearings or azimuths and assume them to be correct in the final adjustment.

This leaves only the two conditions:

(*b*) Sum of latitudes equal zero.

(*c*) Sum of departures equal zero.

That is,

$$\left.\begin{array}{l} l_1 \cos. B_1 + l_2 \cos. B_2 + l_3 \cos. B_3 + = 0 \\ l_1 \sin. B_1 + l_2 \sin. B_2 + l_3 \sin. B_3 + = 0 \end{array}\right\} \dots\dots\dots\dots (10)$$

where the total corrections are to be applied on the basis of inaccuracy in chaining.

In order to derive these corrections on the basis of least squares, denote the observed distances by M_1, M_2, M_3, . . . , and the required corrections by v_1, v_2, v_3, . . . The corrected distances will be

$$l_1 = M_1 + v_1,\ l_2 = M_2 + v_2,\ l_3 = M_3 + v_3 \dots$$

Substituting in (10),

$$(M_1 + v_1) \text{ cos. } B_1 + (M_2 + v_2) \text{ cos. } B_2 + \ldots = 0$$

$$(M_1 + v_1) \text{ sin. } B_1 + (M_2 + v_2) \text{ sin } B_2 + \ldots = 0, \text{ or}$$

$$\left.\begin{aligned} v_1 \text{ cos. } B_1 + v_2 \text{ cos. } B_2 + v_3 \text{ cos. } B_3 + \ldots + q_1 = 0 \\ v_1 \text{ sin. } B_1 + v_2 \text{ sin. } B_2 + v_3 \text{ sin. } B_3 + \ldots + q_2 = 0 \end{aligned}\right\} \ldots . (11)$$

where

$$q_1 = M_1 \text{ cos. } B_1 + M_2 \text{ cos. } B_2 + M_3 \text{ cos. } B_3 + \ldots = \text{error in latitude,}$$

$$q_2 = M_1 \text{ sin. } B_1 + M_2 \text{ sin. } B_2 + M_3 \text{ sin. } B_3 + \ldots = \text{error in departure.}$$

For convenience, change (11) to

$$\left.\begin{aligned} v_1 \frac{L_1}{l_1} + v_2 \frac{L_2}{l_2} + v_3 \frac{L_3}{l_3} + \ldots + q_1 = 0 \\ v_1 \frac{D_1}{l_1} + v_2 \frac{D_2}{l_2} + v_3 \frac{D_3}{l_3} + \ldots + q_2 = 0 \end{aligned}\right\} \ldots\ldots\ldots . (12)$$

where $L_1, L_2, \ldots, D_1, D_2, \ldots,$ denote latitudes and departures.

Aside from (12) we must also have $v_1{}^2 + v_2{}^2 + v_3{}^2 + \ldots$ a minimum, for equal accuracy in chaining the different lines; or, if the accuracy in chaining be assumed to decrease as the square root of the distance,

$$\frac{v_1^2}{l_1} + \frac{v_2^2}{l_2} + \frac{v_3^2}{l_3} + \ldots = \text{minimum.}$$

Differentiating,

$$\frac{v_1}{l_1} dv_1 + \frac{v_2}{l_2} dv_2 + \frac{v_3}{l_3} dv_3 + \ldots = 0 \ldots\ldots\ldots\ldots . (13)$$

If the dv's were independent, their coefficients would have to separately equal zero for (13) to hold true. But the v's are connected by (12). Differentiating (12),

$$\left.\begin{aligned} \frac{L_1}{l_1} dv_1 + \frac{L_2}{l_2} dv_2 + \frac{L_3}{l_3} dv_3 + \ldots = 0 \\ \frac{D_1}{l_1} dv_1 + \frac{D_2}{l_2} dv_2 + \frac{D_2}{l_2} dv_2 + \ldots = 0 \end{aligned}\right\} \ldots\ldots\ldots\ldots (14)$$

If we eliminate a dv in (13) for each of (14), the remaining dv's will be independent, and hence their coefficients will separately equal zero. This elimination is best done by the method of indeterminate multipliers, *i. e.*, multiply the first of (14) by x, the second by y, and (13) by — 1, and add,

$$\left(x \frac{L_1}{l_1} + y \frac{D_1}{l_1} - \frac{v_1}{l_1}\right) dv_1 + \left(x \frac{L_2}{l_2} + y \frac{D_2}{l_2} - \frac{v_2}{l_2}\right) dv_2 + \ldots = 0 \ldots (15)$$

Now give x and y such values that the coefficients of two of the dv's will be zero, thus eliminating them. The remaining dv's will be independent, and hence their coefficients will be zero. This makes the coefficients of all the dv's in (15) equal zero, giving

$$\left.\begin{aligned} x\frac{L_1}{l_1} + y\frac{D_1}{l_1} - \frac{v_1}{l_1} &= 0 \\ x\frac{L_2}{l_2} + y\frac{D_2}{l_2} - \frac{v_2}{l_2} &= 0 \\ x\frac{L_3}{l_3} + y\frac{D_3}{l_3} - \frac{v_3}{l_3} &= 0 \end{aligned}\right\}\quad\ldots\ldots\ldots\ldots\ldots\ldots(16)$$

To find x and y, multiply the first of (16) by L_1, the second by L_2, . . . , and add; then by D_1, D_2, . . . , and add; then by (12)

$$\left.\begin{aligned} \Sigma\left(\frac{L^2}{l}\right)x + \Sigma\left(\frac{L\,D}{l}\right)y + q_1 &= 0 \\ \Sigma\left(\frac{L\,D}{l}\right)x + \Sigma\left(\frac{D^2}{l}\right)y + q_2 &= 0 \end{aligned}\right\}\quad\ldots\ldots\ldots\ldots(17)$$

Σ, as usual, denoting the summation of a number of similar terms,

$$i.\ e.,\ \Sigma\left(\frac{L^2}{l}\right) = \frac{L_1^2}{l_1} + \frac{L_2^2}{l_2} + \frac{L_3^2}{l_3} + .$$

Solving,

$$\left.\begin{aligned} x &= \frac{q_2\,\Sigma\left(\frac{L\,D}{l}\right) - q_1\,\Sigma\left(\frac{D^2}{l}\right)}{\Sigma\left(\frac{D^2}{l}\right)\Sigma\left(\frac{L^2}{l}\right) - \Sigma\left(\frac{L\,D}{l}\right)^2} \\ y &= \frac{q_1\,\Sigma\left(\frac{L\,D}{l}\right) - q_2\,\Sigma\left(\frac{L^2}{l}\right)}{\Sigma\left(\frac{D^2}{l}\right)\Sigma\left(\frac{L^2}{l}\right) - \Sigma\left(\frac{L\,D}{l}\right)^2} \end{aligned}\right\}\quad\ldots\ \ldots\ldots(18)$$

Substituting in (16),

$$\left.\begin{aligned} v_1 &= L_1\,x + D_1\,y \\ v_2 &= L_2\,x + D_2\,y \\ &\ldots\ldots\ldots\ldots\ldots \end{aligned}\right\}\quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(19)$$

Adding, $\Sigma\,(v) = x\,\Sigma\,(L) + y\,\Sigma\,(D),\ = 0$, nearly. . . . . (20)

Also,

$$\left.\begin{aligned} v_{L_1} &= \frac{L_1}{l_1}\,v_1 = \frac{L_1^2}{l_1}\,x + \frac{L_1\,D_1}{l_1}\,y \\ v_{L_2} &= \frac{L_2}{l_2}\,v_2 = \frac{L_2^2}{l_2}\,x + \frac{L_2\,D_2}{l_2}\,y \\ &\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \end{aligned}\right\}\quad\ldots\ldots\ldots\ldots(21)$$

$$\left.\begin{aligned} v_{D_1} &= \frac{D_1}{l_1}\,v_1 = \frac{L_1\,D_1}{l_1}\,x + \frac{D_1^2}{l_1}\,y \\ v_{D_2} &= \frac{D_2}{l_2}\,v_2 = \frac{L_2\,D_2}{l_2}\,x + \frac{D_2^2}{l_2}\,y \\ &\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \end{aligned}\right\}\quad\ldots\ldots\ldots\ldots(22)$$

with, by (17), $\Sigma\,(v_{\mathrm{L}}) = -\,q_1$ and $\Sigma\,(v_{\mathrm{D}}) = -\,q_2$. . . . . (23)

Having adjusted the transit work, or the angles, to geometrical consistency, by distributing the small error of closure equally among the angles, and having computed the co-ordinates, Formulas (18) to (23) give the method of adjustment of the co-ordinates and of the measured sides by least squares. In deriving these formulas the assumption made by Dr. Bowditch, that the inaccuracy in chaining increases as the square root of the distance, has been retained. The application is quite simple, as all the terms are made up from the latitudes, departures and distances already entered upon the co-ordinate sheet, while the multiplications and divisions can be made with the ordinary slide rule, retaining only three figures.

In order to equalize numbers, so as to retain the same number of decimal places throughout, $100\,l$ is used in place of l in (18), and the change carried through, as follows:

$$\left.\begin{aligned} x' &= \frac{q_2\,\Sigma\left(\frac{L\,D}{100\,l}\right) - q_1\,\Sigma\left(\frac{D^2}{100\,l}\right)}{\Sigma\left(\frac{D^2}{100\,l}\right)\Sigma\left(\frac{L^2}{100\,l}\right) - \Sigma\left(\frac{L\,D}{100\,l}\right)^2} \\ y' &= \frac{q_1\,\Sigma\left(\frac{L\,D}{100\,l}\right) - q_2\,\Sigma\left(\frac{L^2}{100\,l}\right)}{\Sigma\left(\frac{D^2}{100\,l}\right)\Sigma\left(\frac{L^2}{100\,l}\right) - \Sigma\left(\frac{L\,D}{100\,l}\right)^2} \end{aligned}\right\} \cdots\cdots\cdots\cdots (18)'$$

$$\left.\begin{aligned} v_1 &= \frac{L_1}{100}\,x' + \frac{D_1}{100}\,y' \\ v_2 &= \frac{L_2}{100}\,x' + \frac{D_2}{100}\,y' \end{aligned}\right\} \cdots\cdots\cdots\cdots (19)'$$

$$\Sigma\,(v) = x'\,\Sigma\,\frac{(L)}{100} + y'\,\Sigma\,\frac{(D)}{100} \cdots\cdots\cdots\cdots (20)'$$

$$\left.\begin{aligned} v_{L_1} &= \frac{L_1}{l_1}\,v_1 = \frac{L_1^2}{100\,l_1}\,x' + \frac{L_1\,D_1}{100\,l_1}\,y' \\ v_{L_2} &= \frac{L_2}{l_2}\,v_2 = \frac{L_2^2}{100\,l_2}\,x' + \frac{L_2\,D_2}{100\,l_2}\,y' \\ &\cdots\cdots\cdots\cdots\cdots\cdots \end{aligned}\right\} \cdots\cdots\cdots\cdots (21)'$$

$$\left.\begin{aligned} v_{D_1} &= \frac{D_1}{l_1}\,v_1 = \frac{L_1\,D_1}{100\,l_1}\,x' + \frac{D_1^2}{100\,l_1}\,y' \\ v_{D_2} &= \frac{D_2}{l_2}\,v_2 = \frac{L_2\,D_2}{100\,l_2}\,x' + \frac{D_2^2}{100\,l_2}\,y' \\ &\cdots\cdots\cdots\cdots\cdots\cdots \end{aligned}\right\} \cdots\cdots\cdots\cdots (22)'$$

$$\Sigma\,(v_L) = -\,q_1, \qquad \Sigma\,(v_D) = -\,q_2. \cdots\cdots\cdots\cdots (23)'$$

With the following notation:

x' and y' may be called auxiliaries;

q_1 = error in latitude;

q_2 = error in departure;

$L_1, L_2, L_3, \dots,$ = latitudes of sides $l_1, l_2, l_3, \dots;$

$D_1, D_2, D_3, \dots,$ = departures of sides $l_1, l_2, l_3, \dots;$

Σ denotes the summation of a number of similar terms;

$v_1, v_2, v_3, \dots,$ = corrections to sides $l_1, l_2, l_3, \dots;$

$v_{L_1}, v_{L_2}, v_{L_3}, \dots, v_{D_1}, v_{D_2}, v_{D_3}, \dots,$ = corrections to latitudes and departures, respectively.

The application of the method is best shown by a problem.

TABLE No. 2.—Problem from Data Previously Given.

Station.	Deflection to the R.	Correction.	Azimuth.	Dist.	Latitude, L.		Departure, D		$\frac{L^2}{100\,l}$	$\frac{D^2}{100\,l}$	$\frac{L\,D}{100\,l}$
					+	−	+	−			
1.......	92° 00′	+0.6′	92° 0.6′	236	....	8.3	235.9	......	0.0	2.36	−0.08
2.......	46 00	0.6	138 1.2	244	....	181.4	163.2	......	1.35	1.09	−1.21
3.......	82 00	0.6	220 1.8	324	....	248.1	....	208.4	1.90	1.38	+1.60
4.......	51 57	0.6	271 59.4	183	6.3	......	....	182.9	0.0	1.83	−0.06
5.......	88 00	0.6	360 0.0	437	437.0	......	....	0.0	4.37	0.0	0.0
	359 57	3.0	Totals ...	......	443.3	437.8	399.1	391.3	7.62	6.66	+0.25
					437.8	......	391.3				
				q_1	$=+5.5$	q_2	$=+7.8$				

The observed angles foot up 3 minutes too small. To each angle 0.6 minute is added, and the azimuths computed with 5–1 as an axis. The latitudes and departures are computed and added as usual, giving $q_1 = +5.5$, and $q_2 = +7.8$. The three columns at the right are used in finding x' and y'. To fill them out, set the slide rule to latitude divided by distance ($L \div l$) for each horizontal line and multiply by one-hundredth of the latitude (0.01 L) for the corresponding term in the $\frac{L^2}{100\,l}$ column; with the same settings multiply by one-hundredth of the departure for the corresponding terms in the $\frac{L\,D}{100\,l}$ column. Then set to departure divided by distance and multiply by one-hundredth of the departure for the $\frac{D^2}{100\,l}$ column. Add the three columns for $\Sigma\left(\frac{L^2}{100\,l}\right)$, $\Sigma\left(\frac{D^2}{100\,l}\right)$, and $\Sigma\left(\frac{L\,D}{100\,l}\right)$, and substitute in (18)′, giving

$$x' = \frac{7.8 \times 0.25 - 5.5 \times 6.66}{6.66 \times 7.62 - (0.25)^2} = -0.68$$

$$y' = \frac{5.5 \times 0.25 - 7.8 \times 7.62}{6.66 \times 7.62 - (0.25)^2} = -1.15.$$

If the corrections to the latitudes and departures only are required, as in computing areas or co-ordinates, use (21)′ and (22)′. To do this, set x' on the slide rule and multiply by each number in the $\frac{L^2}{100\,l}$ column for the first term in each latitude correction, and by each $\frac{L\,D}{100\,l}$ for the first term in each departure correction. Then set to the value of y', and multiply by each $\frac{L\,D}{100\,l}$ for the second term in each latitude correction, and by each $\frac{D^2}{100\,l}$ for the second term in each departure correction, giving:

$$\begin{array}{llll}
v_{L_1} = 0.0 + 0.09 = +0.1 & & v_{D_1} = +0.05 - 2.71 = -2.7 \\
v_{L_2} = -0.92 + 1.39 = +0.4 & & v_{D_2} = +0.82 - 1.25 = -0.4 \\
v_{L_3} = -1.29 - 1.84 = -3.1 & & v_{D_3} = -1.09 - 1.59 = -2.7 \\
v_{L_4} = 0.0 + 0.07 = +0.1 & & v_{D_4} = +0.04 - 2.10 = -2.0 \\
v_{L_5} = -2.97 + 0.0 = -3.0 & & v_{D_5} = 0.00 + 0.0 = 0.0
\end{array}$$

Check, (23)′

$$\Sigma(v_L) = -q_1 = -5.5 \qquad \Sigma(v_D) = -q_2 = -7.8$$

If the corrections to the distances only are required, as for a geometrically consistent description or record map, use (19)′; the x' setting of the slide rule giving all the first terms when multiplied by one-hundredth of the latitudes, and the y' setting the second terms when multiplied by one-hundredth of the departures. Thus:

$$\begin{array}{lll}
v_1 = +0.06 & -2.72 & = -2.66 \\
v_2 = +1.23 & -1.88 & = -0.65 \\
v_3 = +1.68 & +2.40 & = +4.08 \\
v_4 = -0.04 & +2.11 & = +2.07 \\
v_5 = -2.97 & +0.0 & = -2.97
\end{array}$$

$$\Sigma(v) = -0.68 \times 0.055 - 1.15 \times 0.078 = -0.13 \text{ by } (20)'$$

If corrected co-ordinates and distances are both required, it will be less work to find the distance corrections first and the co-ordinate corrections from these by the first portions of (21)′ and (22)′.

TABLE No. 3.—Problem from Actual Survey.

Angles closed without adjustment.

Station.	Bearing.	Distance.	Latitude, L.		Departure, D.		$\frac{L^2}{100\,l}$	$\frac{D^2}{100\,l}$	$\frac{L\,D}{100\,l}$
			+	−	+	−			
1.......	N. 44° 38.5′ E.	287.24	201.37	....	201.83	....	1.45	1.42	1.44
2.......	N. 52 42.5 E.	451.75	273.70	....	359.40	....	1.65	2.85	2.18
3.......	S. 2 00 W.	921.60	....	921.04	....	32.16	9.20	0.01	0.32
4.......	N. 88 34 W.	212.00	5.30	....	....	211.93	0.00	2.11	−0.05
5.......	S. 88 50.5 W.	317.30	....	6.41	....	317.24	0.01	3.17	0.06
6.......	North........	443.60	443.60	....	....	....	4.44	0.00	0.00
	Totals.....	....	926.97	927.45 926.97	561.23	561.33 561.23	16.75	9.56	3.95
			$q_1 =$	− 0.48	$q_2 =$	− 0.10			

$$x' = \frac{-0.10 \times 3.95 + 0.48 \times 9.56}{160 - 15.55} = +0.029$$

$$y' = \frac{-0.48 \times 3.95 + 0.10 \times 16.75}{160 - 15.55} = -0.001$$

$v_1 = +0.05;\quad v_{L_1} = +0.04;\quad v_{D_1} = +0.04$

$v_2 = +0.08;\quad v_{L_2} = +0.05;\quad v_{D_2} = +0.06$

$v_3 = -0.26;\quad v_{L_3} = +0.26;\quad v_{D_3} = +0.01$

$v_4 = 0.00;\quad v_{L_4} = 0.00;\quad v_{D_4} = 0.00$

$v_5 = 0.00;\quad v_{L_5} = 0.00;\quad v_{D_5} = 0.00$

$v_6 = +0.13;\quad v_{L_6} = +0.13;\quad v_{D_6} = 0.00$

$\Sigma\,(v) = 0.00;\quad \Sigma\,(v_L) = +0.48 = -q_1;\quad \Sigma\,(v_D) = +0.11 = -q_2$

In some cases base or reference lines and stations are carefully located, and the other work adjusted to them; in others, a survey is extended after an adjustment has been made which it is desired not to disturb. These cases are treated by omitting the terms and corrections for the perfect lines, which forces all the corrections into the unadjusted parts.

Thus, in the foregoing problem, if 6–1 be regarded as perfect,

$$\Sigma\left(\frac{L^2}{100\,l}\right) = 12.31;\ \Sigma\left(\frac{D^2}{100\,l}\right) = 9.56;\ \Sigma\left(\frac{L\,D}{100\,l}\right) = 3.95.$$

$$x = \frac{-0.10 \times 3.95 + 0.48 \times 9.56}{9.56 \times 12.31 - (3.95)^2} = +0.041$$

$$y = \frac{-0.48 \times 3.95 + 0.10 \times 12.31}{9.56 \times 12.31 - (3.95)^2} = -0.007$$

$$\begin{array}{lll}
v_1 = +0.07; & v_{L_1} = +0.05; & v_{D_1} = +0.05 \\
v_2 = +0.09; & v_{L_2} = +0.05; & v_{D_2} = +0.07 \\
v_3 = -0.38; & v_{L_3} = +0.38; & v_{D_3} = +0.01 \\
v_4 = +0.01; & v_{L_4} = 0.00; & v_{D_4} = -0.01 \\
v_5 = +0.02; & v_{L_5} = 0.00; & v_{D_5} = -0.02 \\
\hline
\Sigma(v) = -0.19; & \Sigma(v_L) = +0.48; & \Sigma(v_D) = +0.10
\end{array}$$

By (20)′, $\Sigma(v) = -0.041 \times 4.44 + 0.007 \times 0.001 = -0.18$, for a check.

The method thus lends itself readily to the fitting of new to old work which has already been adjusted.

The application of the method of adjustment is given in considerable detail so that it can be used mechanically the same as the old compass survey method without looking up its theoretical basis. It cannot be stated so concisely as the old, and the numerical work involves more labor if corrected co-ordinates only are required. In case corrected distances are required, to give with the bearings geometrically consistent data for a record map or description, this requires less labor than the old method, for the corrected distances are used directly with the bearings, while in the old method neither corrected distances nor bearings can be obtained without a special computation after the co-ordinates have been adjusted.

The method has a good theoretical basis for the conditions assumed, viz.: small errors of closure for the angles and an inaccuracy of chaining increasing as the square root of the distance, while the old method has none for transit work.

Vol. XXVI. DECEMBER, 1900. No. 10.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

PAPERS AND DISCUSSIONS.

Note.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

THE CONSTRUCTION OF GRAVITY SAND FILTERS AT NYACK, N. Y.

By G. N. Houston, Assoc. M. Am. Soc. C. E.

To be Presented February 20th, 1901.

The Village of Nyack is situated on the west bank of the Hudson River, about 28 miles from New York City. The Villages of South Nyack and Upper Nyack adjoin it on either side, and are supplied by it with water. The combined population is about 8 000.

These villages were originally supplied from springs by gravity, but in 1884 the company then owning the works found it necessary to increase this supply by pumping from Hackensack Creek, the present source of four-fifths of the supply.

As the proportion of Hackensack Creek water to spring water increased, dissatisfaction among the consumers likewise increased, until, in 1893, the Village of Congers constructed a shallow lake by damming a branch of the stream and flooding an area which had never been cleared of the stumps or surface soil. The water then became unbearable, and the villages applied to the State Board of Health for a remedy. Accordingly, the Board made a report in 1894

Note.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers with discussion in full will be published in *Transactions*.

advising the water company to filter the supply. Nothing, however, was done at that time.

In July, 1897, the Village of Nyack acquired the plant of the Nyack Water-Works Company by condemnation proceedings, and began to consider the improvement of the supply.

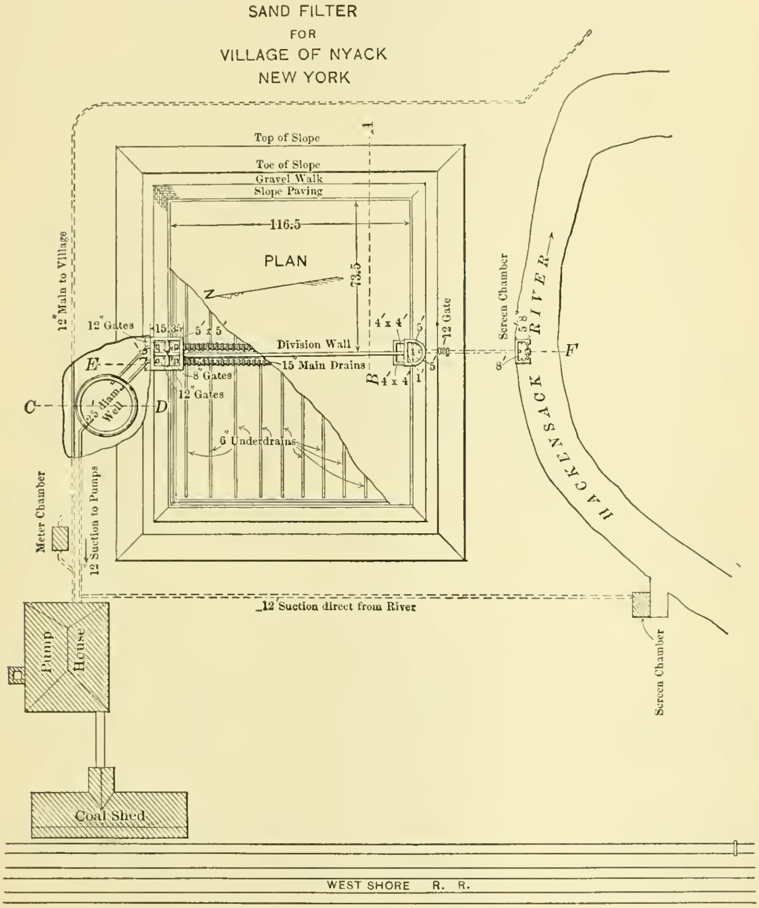

Fig. 1.

Driven wells were tried and failed. A gravity supply from a more sparsely settled water-shed was considered, but the estimated cost exceeded the available means. The filtration of the present supply was then recommended and adopted.

Description of Plant.

The filter is of the open, gravity, sand type, and was designed for slow filtration. It is located in a swamp on the Hackensack River, about 2½ miles west of the village, and just north of the West Nyack Station on the West Shore Railroad (Fig. 1).

It consists of two rectangular beds of equal size, with a combined filtering area of 16 400 sq. ft., or 0.38 acre, and a pure-water reservoir having a capacity of 44 000 galls. It is built wholly in excavation below the level of the creek, and is protected by earth embankments from high water, which floods the surrounding ground. Several cross-sections are shown in Fig. 2.

The enclosing walls are of concrete to a height of about 3 ft. 8 ins. above the bottom. Above these walls a vitrified brick paving is laid at a slope of 1½ to 1, and to a height of 4 ft. above the wall.

The bottom is of concrete, and the regulating and intake chambers are of brick. The division wall above the sand is of brick; below the sand it is of concrete.

The filtering material consists of 3 ft. of sand underdrained by 1 ft. of gravel and by 6-in. tile pipe. Each bed has a main drain of tile pipe leading to the regulating chamber.

The pure-water well is built of brick, and the bottom is of concrete. It is entirely separated from the filter, but is connected with the regulating chamber by a 12-in. cast-iron pipe.

Details of Construction.

The excavation was begun during dry weather of August, 1897. After removing 2 ft. of black muck on top, a stiff damp red clay was encountered, and the deeper the excavation was carried, the more wet and tenacious became the clay, and the more difficult it became to handle. Shovels and spades were used to cut it in blocks which were then thrown on wagons by the hands. Teaming was impossible, except on roadways of old railway ties or plank.

The depth of the cut to be made averaged 12.5 ft. After a depth of 10 ft. was reached, the sides of the excavation, which up to this time had stood nearly vertical, cracked back from the face a distance of 2 to 4 ft., and subsided, making a corresponding elevation in the adjacent bottom, which had become very soft and puddled by teaming over it.

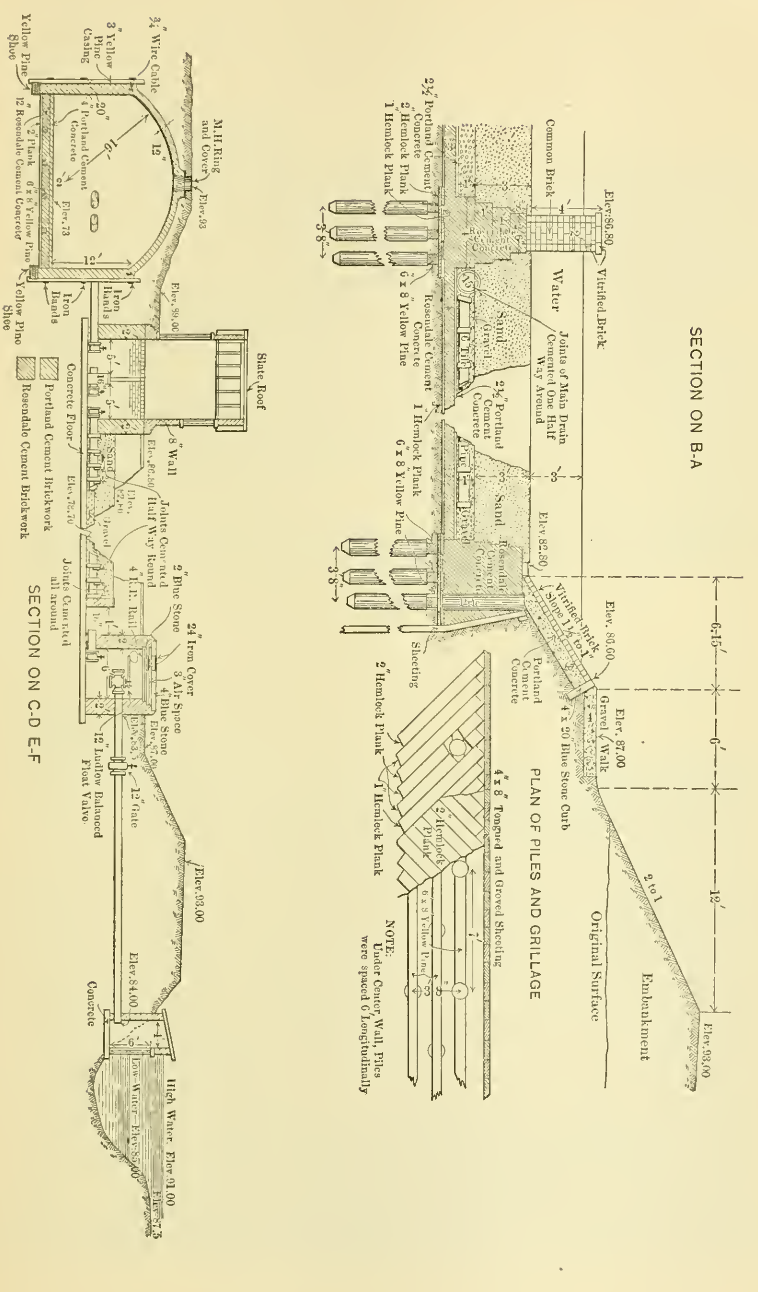
SECTION ON B-A
Elev. 86.80
Vitrified Brick
Common Brick
Water
Joints of Main Drain Cemented One Half Way Around
Sand
Gravel
Tile
Pipe
Rosendale Cement Concrete
2¼" Portland Cement Concrete
2" Hemlock Plank
1" Hemlock Plank
6" x 8" Yellow Pine
3'-8"
Elev. 82.80
Vitrified Brick, Slope 1½ to 1
Elev. 86.60
Portland Cement Concrete
Sheeting
4 x 20 Blue Stone Curb
Gravel Walk
Elev. 87.00
6.15'
6'
12'
2 to 1
Original Surface
Embankment
Elev. 93.00
PLAN OF PILES AND GRILLAGE
4" x 8" Tongued and Groved Sheeting
2" Hemlock Plank
1" Hemlock Plank
6 x 8 Yellow Pine
NOTE: Under Center Wall, Piles were spaced 6' Longitudinally
SECTION ON C-D E-F
¾" Wire Cable
3" Yellow Pine Casing
Yellow Pine Shoe
M.H. Ring and Cover
Elev. 93
12"
16'
20"
4" Portland Cement Concrete
2" Plank
12" Rosendale Cement Concrete
6" x 8" Yellow Pine
Elev. 73
Iron Bands
Elev. 90.00
Slate Roof
8" Wall
Elev. 86.80
Concrete Floor
Elev. 78.70
Joints Cemented Half Way Round
2" Blue Stone
4" R.R. Rail
Joints Cemented all around
24" Iron Cover
3" Air Space
4" Blue Stone
Elev. 87.00
12" Ludlow Balanced Float Valve
12" Gate
Elev. 93.00
Elev. 84.00
Concrete
High Water. Elev. 91.00
Low Water Elev. 85.00
Elev. 87.5
Portland Cement Brickwork
Rosendale Cement Brickwork

FIG. 2.

To remedy this difficulty, excavating the easterly end at a slope of $1\frac{1}{2}$ to 1 was tried, with a like result when the same depth was reached, and it became evident that, with this method of excavation, the required depth could not be reached.

The contractor had taken the excavation at the low price of 29 cents per cubic yard. It was evident that he was losing money on this part of the work, and, becoming somewhat discouraged, he finally abandoned it.

Rudolph Hering, M. Am. Soc. C. E., was then asked to report on the situation for the village. By his advice, soundings were made over the entire area. These were made with an iron rod 1 in. in diameter and 30 ft. long, on which was arranged a sliding weight. This weight was made of a short section of 6-in. cast-iron water pipe, in the center of which was a piece of $1\frac{1}{4}$-in. wrought-iron pipe, the space between being filled with lead. On the bottom was an iron plate, the whole weighing about 130 lbs.

The weight was lifted by two men and allowed to fall on an adjustable clamp. The height to which it was lifted varied from 3 to 4 ft., and a record was taken of the depth penetrated by each ten blows. The upper part of the rod was steadied by a tripod. To withdraw the rod a 3-ton block and fall was used.

These soundings showed the presence of water-bearing gravel strata varying from 2 ft. at the westerly end to 20 ft. at the easterly end below the proposed bottom of the filter. Mr. Hering then advised continuing the construction by the use of sheet-piling and sustaining piles.

Before the sheet-piling could be started, the creek broke through the bank and flooded the excavation. This made it necessary to drive a line of 4 x 8-in. tongued and grooved spruce sheeting between the creek and the excavation. This sheeting was driven to a depth of 3 to 4 ft. below the proposed bottom of the filter. The water was then pumped out, and the whole area surrounded by a single row of sheet-piling of the same kind. The latter sheeting was driven within the excavation and 1 ft. outside of the foundation line of the filter. Sustaining piles were then driven on the proposed site of the walls.

In driving the sheeting it was found that in most places it could be driven clear through the gravel strata into softer material below. For this reason the round piles were driven with blunt ends of at least

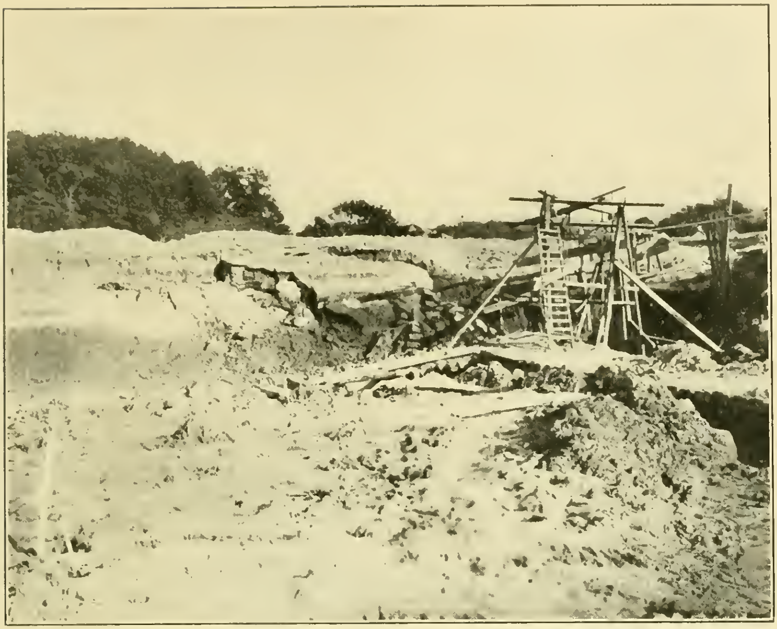

FIG. 1.—VIEW OF EXCAVATION, SHOWING SUBSIDENCE OF BANKS.

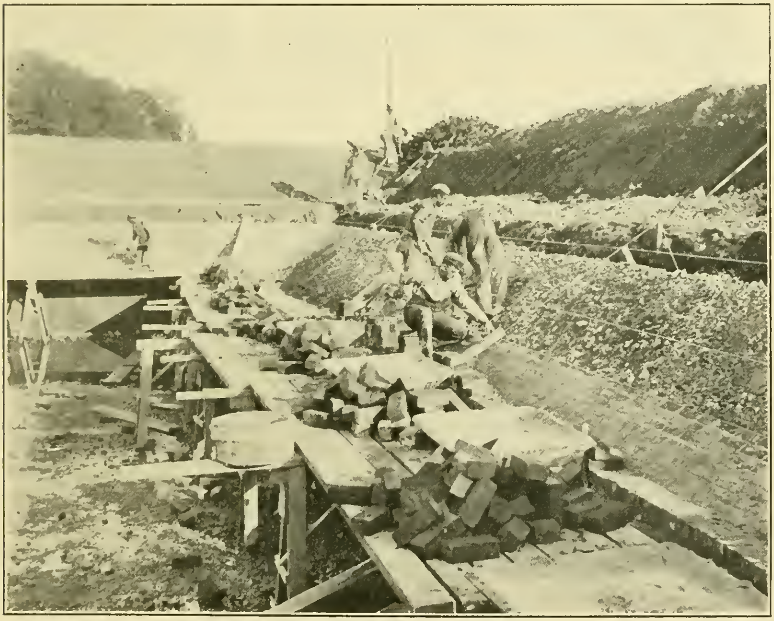

FIG. 2.—LAYING VITRIFIED BRICK SLOPE.

6 ins. diameter. Although some of the 332 piles thus driven evidently stopped at the gravel strata, fully two-thirds of the number depend largely on friction for sustaining power.

The maximum weight sustained by each pile under the outside wall is about 4 tons; under the division wall, 5½ tons. The sheeting cost 5 cents per foot, board measure, driven, and the cost of the sustaining piles averaged $4.42 each, in place.

Just at this time, April, 1898, the funds available for this work gave out and the construction came to a standstill. Soon after, during high water, the excavation was flooded a second time. It remained in this condition until July, 1899, when the work was again taken up.

The original plans and specifications were modified to meet the new conditions, and a new contract was let. The changes were as follows:

First.—The level of the whole bed was raised 1 ft., and the depth of the filtering material was reduced from 5 to 4 ft. This made a total raise of 2 ft. in the bottom of the filter, and reduced the average cut to 10.5 ft.

Second.—Concrete was substituted for brickwork in the walls below the level of the top of the sand, and slope paving was substituted for the vertical walls above this level.

Third.—All brickwork exposed to the elements was faced with vitrified brick.

After pumping out the water, the excavation was carried down to the proper depth on the site of the outside walls, the piles were sawed off and capped, and the walls were started before attempting to excavate the interior.

The sheet piling was exposed by this excavation for a depth of 5 to 7 ft., and was seen to be practically water-tight. It had a tendency to crowd in at the top, on account of the pressure behind it, and, in order to brace it, the outside row of sustaining piles was left standing. Inclined braces, running to a footing of railroad ties, were also found necessary.

In one place, where the sheeting had been pushed over so far as to interfere with proper construction, it was forced back part way by screw jacks after relieving some of the pressure by excavating behind it.

At the easterly end derricks and buckets were used to handle the excavated material and to place the concrete, but were not found necessary after the wall at that end was completed. The interior was excavated with teams. Very little water was encountered until the walls and floor of the east half were nearly completed, when a large spring broke out in the center of the excavation at a point over which all the teams bringing material for concrete had passed and had consequently puddled the clay. This was stopped at this point, but broke through at a point about 20 ft. distant.

Underdrains were laid leading the water to the pure-water well, which had been sunk to a depth somewhat lower than the filter, and was kept dry by a centrifugal pump.

This and a similar spring which broke through later were left until the beds were otherwise completed, and were finally stopped by filling with from 10 to 12 cu. yds. of field stone and concreting over it, leaving a 15-in. vitrified pipe through the concrete for a drain. When the concrete had set, a 6-in. pipe was placed inside the 15-in. pipe, and bagging was rammed down around it and loaded with concrete, which was covered with bagging, to prevent the water which dropped over the edge from washing out the cement. It was found that there was not head enough to raise this water above the sand line, and the spring was stopped up with cement bags and concrete.

The piles were capped with 6 x 8-in. yellow pine stringers spiked to each pile by two 14-in. drift bolts. Where the ends of these stringers met they were joined with a scarf joint and bolt and nut.

The piles in the row next to the sheeting were notched to receive the stringers, as shown in Fig. 2. On these stringers, and at an angle of 45° with them, 2-in. hemlock planks were nailed. On top of these, and at an angle of 90° with the former planks, were nailed 2-in. and 1-in. hemlock plank, laid alternately, thus making a well-braced platform sufficiently rough to give a good footing for the walls.

The cost of the piles, capping and platform averaged $3 per foot of wall sustained.

The forms for the walls were then erected. They were made from 2-in. hemlock plank. In some instances forms were used for the back of the wall, but in most of the construction the concrete was carried back against the sheeting, and the piles in the outside row were concreted into the wall.

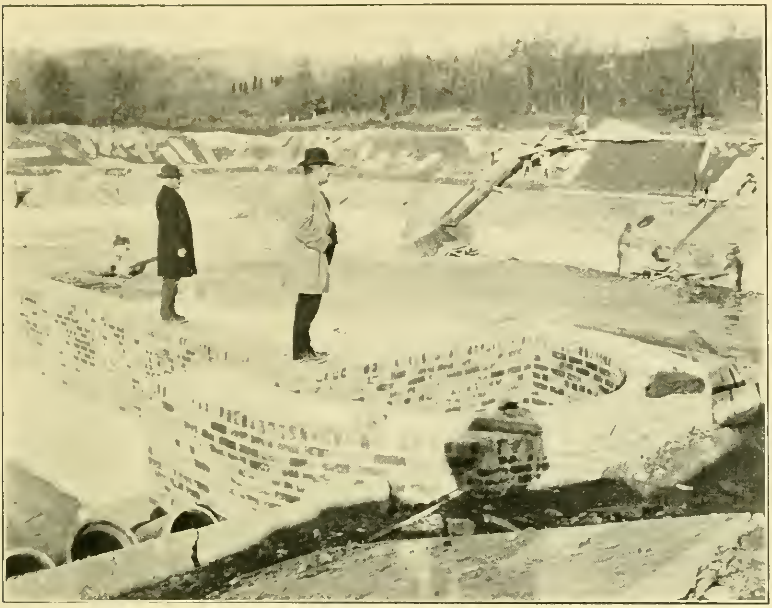

FIG. 1.—PLACING GRAVEL IN EAST FILTER BED.

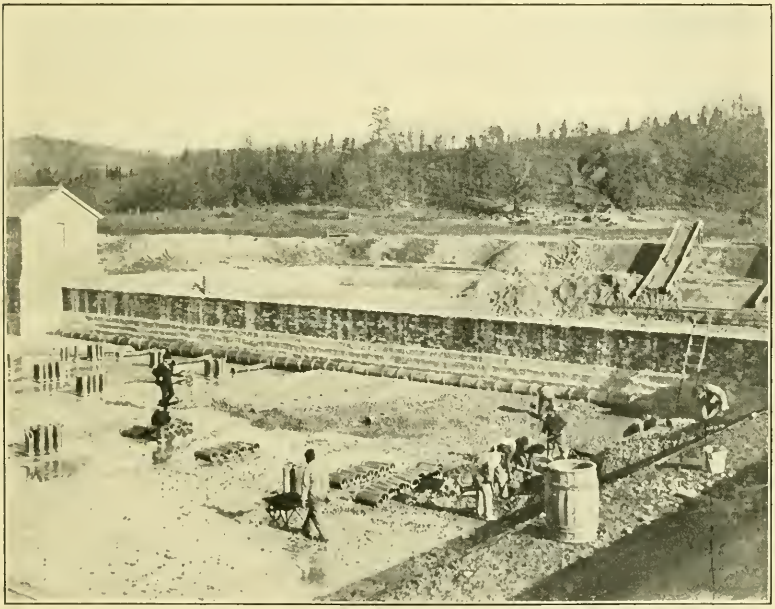

FIG. 2.—UNDERDRAINS AND MAIN COLLECTOR IN WEST FILTER BED.

In some instances the inclined braces supporting the sheeting were also concreted into the wall and left until just previous to putting in the sand, when they were either taken out and the hole filled up with concrete, or sawed off and cut back from the face of the wall at least 6 ins. and covered with Portland cement concrete.

The face of the outside walls below the sand line was stepped in 2 ins., and the division wall 3 ins. in each foot of rise. With the exception of the division wall, which was of uniform dimensions throughout, the concrete walls varied in thickness according to their location. The concrete in the south wall averaged 0.8 cu. yd. per lineal foot; that in the east wall averaged 0.33 cu. yd. per lineal foot, and that in the north and west walls 0.7 cu. yd. per lineal foot. The division wall averaged 0.61 cu. yd. per lineal foot.

The floors were placed on 1-in. hemlock plank, laid on the clay to prevent the concrete from mixing with the soft bottom.

They were made of Rosendale cement concrete 0.66 ft. thick, topped with Portland cement concrete having an average thickness of 0.22 ft.

All concrete was mixed by hand. Rosendale cement concrete for the walls and floor was composed of 1 part cement, 2 parts sand and 6 parts broken limestone, varying from ½ in. to 2½ ins. in greatest dimensions. The Portland cement concrete in the floors was mixed in the proportions of 1 part cement, 3 parts sand and 5 parts ¾-in. broken limestone.

The faces of the concrete walls were first pointed up with 2 to 1 Rosendale cement, and then plastered with 2 to 1 Portland cement.

The floors cost $1.50 per square yard in place. The concrete walls cost $4.40 per cubic yard in place. The labor of mixing and depositing the concrete for the walls was 1 man, 0.42 day per cubic yard. For the Rosendale cement concrete in the floors, 1 man, 0.32 day per cubic yard.

The division wall, above the sand line, was built of brick in Portland cement, and faced with vitrified brick. The slope paving was laid on a foundation of 8 ins. of Portland cement concrete, composed of 1 part cement, 3 parts sand and 7 parts broken limestone, varying from ½ in. to 2½ ins. in greatest dimension. The vitrified brick slope paving and all other brickwork, with the exception of that in the house over the regulating chamber, was laid in 3 to 1 Portland cement mortar.

The average cost of the exterior concrete wall, slope paving and curb was $5 per lineal foot. The average cost of the division wall was $5.19 per lineal foot. The ordinary brickwork in the walls cost $8 per cubic yard. The vitrified brickwork in the walls cost $8.40 per cubic yard.

The intake chamber extends outside of the first row of sheeting, and is of circular form on the outside, to better withstand the pressure.

The filtering gravel is of the following sizes: The bottom 6 ins. in depth varies from 3 ins. to 1 in. in greatest diameter; the next 3 ins., from 1 to ½ in.; the top 3 ins., ½ in. and less. With the exception of a small portion of the top layer, the gravel in the east half is of crushed trap rock and hard field stone; in the west half it is washed gravel from Cow Bay, Long Island.

The sand was obtained from Cow Bay, and was delivered in barges at the dock at Nyack, from which it was carted to the beds in wagons. It was placed in the beds as received, as was also the crushed stone and gravel. Both sand and gravel cost $2.15 per cubic yard in place.

During the first week the filter was operated the water was wasted, on account of its being quite turbid and tasting of the cement. After that, it was pumped into the reservoirs, although still quite turbid. After about a month it became decidedly better, and at the end of the second month the turbidity could scarcely be noticed in an ordinary glass, but still showed slightly in the regulating chamber, where there was a depth of about 8 ft.

After three months the water was free from all turbidity, but had a slight color. In a glass or small vessel it appeared to be colorless, but where there was any considerable depth, as in the regulating chamber, it could be easily noticed.

In the intake chamber there is an ordinary 12-in. Ludlow balanced float valve, which regulates the depth of water over the sand to 3 ft., when the pumps are running; otherwise, 3½ ft.

The rate of filtration is regulated by the pumps, which draw from the pure-water well and supply the reservoirs in the village. The pumps are in use almost every day for at least 9 hours, and run at a uniform rate while in operation.

The maximum consumption of water is at the rate of about 630 000 galls. per day, which, if one bed only were used, would give a maximum draft of about 3 326 000 galls. per acre per day. This condition, how-

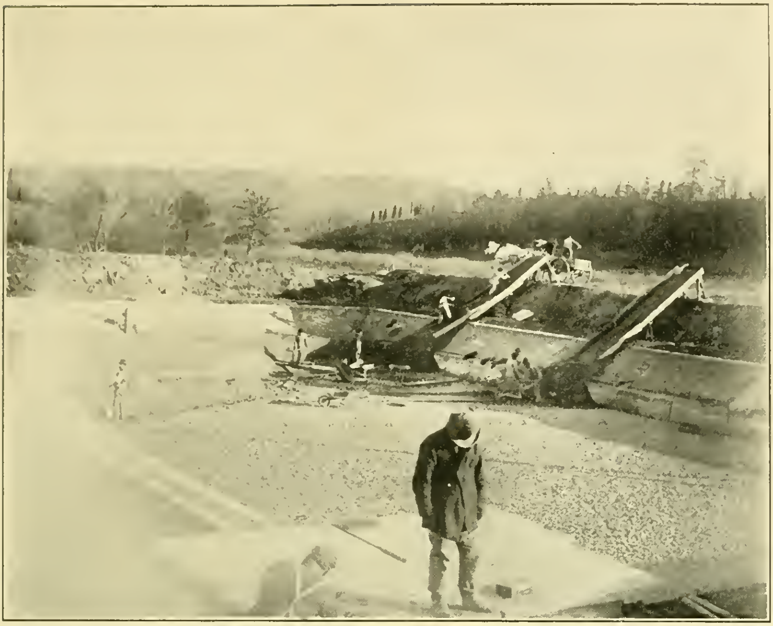

Fig. 1.—Placing Sand in East Filter Bed.

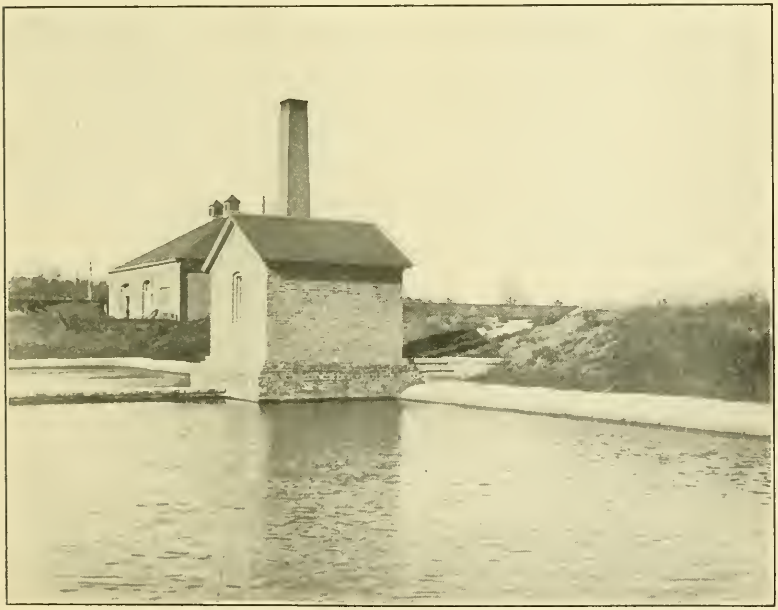

Fig. 2.—Completed Filter Basins and Regulating Chamber.

ever, is not realized in practice, as both beds are used at the same time, except when one is being cleaned.

The development of the springs before mentioned is reducing to some extent the amount of filtered water required, and the total consumption is being decreased by the gradual introduction of meters.

The pure-water well was sunk on a shoe made of three rings of 4-in. yellow pine bolted together. Each ring is composed of six sections. This makes a solid shoe of 25 ft. internal and 28.5 ft. external diameter.

An excavation, about 6 ft. deep, was made on the site of the well, and the shoe was put together in the bottom. Around this shoe was erected a tub or casing of 3 x 6-in. x 15-ft. yellow pine plank, spiked to the shoe and held in place by three iron hoops drawn tight by bolts and nuts. The 20-in. wall was then built on this shoe to a height of 10 feet.

Excavation with derricks and buckets was then begun, but, later, the second contractor erected a centrifugal pump, and, using a jet of water from the mains under about 150 lbs. pressure, softened the clay and pumped it out.

The floor was made by laying 2-in. planks on the bottom, and over them 6 x 8-in. yellow pine timbers, inserted in holes cut in the brickwork just above the shoe. Rosendale cement concrete 1 ft. thick and of the same character as that on the bottom of the filter, was then laid on the bottom, thus covering the 6 x 8-in. stringers 4 ins. deep. On this a 4-in. layer of Portland cement concrete was placed.

The well was covered with a spherical dome of 6 ft. rise, the radius of the sphere being 16 ft. To relieve the thrust of this dome, a $\frac{3}{4}$-in. cable was built in at the spring line. Of this cable, 125 ft. were used, it being double on the side toward the filter.

The embankments were formed with the material excavated from the original surface, without cleaning or grubbing. Where it was found necessary to make embankments upon which the slope paving was to rest great care was taken to have it thoroughly compacted by tamping and then settling with water. Nothing was done to compact the embankments above the slope paving, except the ordinary teaming over them. They were designed and constructed originally on a slope of $1\frac{1}{2}$ to 1, with the walk 1 ft. above the curb. They were completed about December, 1899, and, therefore, could not be seeded. The clay, on thawing in the spring, became semi-liquid and ran until it stood at a slope of from 2 to 1 to 3 to 1. A great deal of it ran over the curb and upon the filter beds which were then being used. This was cleaned off, and then the banks were cut back to a 2 to 1 slope, topped with 1 ft. of loam, and seeded, and the grade of the walk was lowered to the top of the curb.

In order to keep the foot of the embankment in place it was found necessary to excavate the walk to the 4-in. sub-grade and fill in with crushed stone; which furnished sufficient weight to prevent the pressure of the embankment from raising the soft material under the walk.

When the beds were cleaned for the second time it was found that the clay had never been thoroughly removed from them. In order to remove it, the sand to a depth of from 1½ to 3 ins. was taken off and replaced with clean sand. The beds were finally completed about May 1st, 1900.

The cost of the filters is shown in the following table:

Sheet piling in place	$3 300
Sustaining piles in place	1 558
Excavation	5 270
Grading and soiling	1 500
Engineering	3 644
Inspection and tests	713
Rosendale cement concrete in floors	1 958
Portland " " "	780
Rosendale " " walls	1 892
Portland " " slope paving	484
Vitrified brick, slope paving	113
Curb in place	250
Underdrains	347
Filtering material	5 524
Hemlock lumber, capping and floors	838
Yellow pine lumber " " "	465
House over regulating chamber	150
Pipe laying, etc.	58
Miscellaneous	250
Total	$29 094

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS AND DISCUSSIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

THE PRESERVATION OF RAILWAY TIES IN EUROPE.

Discussion.*

By Messrs. J. JAMES R. CROES, W. B. REED, G. W. TILLSON, MENDES COHEN, SAMUEL WHINERY and SAMUEL M. ROWE.

J. JAMES R. CROES, M. Am. Soc. C. E.—This interesting paper contains many valuable facts and figures, but the variety of notation used in presenting them renders it somewhat difficult to compare the results attained in different countries and by different processes of preservation. Thus, in Table No. 1, which gives data from English railroads, the amount of creosote used is given in pounds per cubic foot, gallons per cubic foot, pounds per tie and gallons per tie, indiscriminately, without any statement as to the relation of the tie, the cubic foot, the pound and the gallon. Then, too, the number of ties renewed annually is given without any reference to the total number of ties in use or the length of the track, except in one case where the number of ties renewed annually per mile is given. So, also, in Table No. 2, giving data of French railroads, the length of track on which the observations were made is not given at all; simply the total number of ties renewed annually. However, the cost of treatment per tie is given uniformly in American cents per tie and that is, after all, what it is necessary to know, in connection with the life of the tie, to determine the relative Mr. Croes.

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*This discussion (of the paper by Octave Chanute, Past-President, Am. Soc. C. E., printed in *Proceedings* for September, 1900) is printed in *Proceedings* in order that the views expressed may be brought before all members of the Society for further discussion.

Communications on this subject received prior to January 26th, 1901, will be printed in a later number of *Proceedings*, and subsequently the whole discussion will be published in *Transactions*.

Mr. Croes. advantage of using different methods of treatment or no treatment at all. As the author well says, it is not economical to spend as much money on the preservation of a cheap tie as might be spent in extending the life of one of great first cost, and, therefore, cheaper and more inferior methods of preservation than are found advantageous in Europe, where the timber costs more, may well be applied in this country.

The author gives as the first two of the leading features of tie treatment in Europe, (1) close inspection of raw ties, rejecting all defects, and (2) thorough seasoning for six to twelve months before treatment. It appears that he has found it desirable to introduce these features in his own works in this country. A number of railroad managers and engineers have found it to their advantage to take the same precaution with reference to the ties to be used in their roads, without treatment. Indeed, some engineers go so far as to say that this preliminary treatment appears to prolong the life of the average tie more than the subsequent injection of a small quantity of cheap chemicals. It would seem as if this question was worth a careful investigation and a comparison of two distinct sections of road, one laid entirely with untreated ties selected and seasoned under cover for a proper length of time, and the other laid with treated ties from some one of the commercial tie plants. One difficulty connected with the determination of the whole question is, as the author says, the fact that it requires nearly half a business lifetime to arrive at any results, and the proportion of an official lifetime is much greater. In carrying out any series of experiments or inspection, uniformity of method is desirable, and that is not easily maintained under changes of administration. From the Society lists for the years 1890 and 1900 it appears that of one hundred members holding the position of chief engineer of a railroad in the former year only 30% held the same position in 1900. Promotion, transfer, resignation or death, had caused the changes of administration, and, in the absence of any uniform and standard system of recording facts and statistics, had doubtless produced changes of method which caused previously collected data to be of little or no use. The valuable papers of Mr. Chanute and Mr. Curtis* emphasize the need of a concert of action among the engineers of railroad maintenance, in the collection and recording of important statistics.

Mr. Reed. W. B. Reed, Assoc. M. Am. Soc. C. E.—There are a few vulcanized ties on the Metropolitan Railway, and, as nearly as the speaker can ascertain, these were laid about eight years ago. In taking out some of them recently, they were found to be so soft that they would not hold a spike. They did not seem to be decayed, but had evidently absorbed more or less moisture from the ground, and were not fit to be used again. On the other hand, some long-leaf Georgia pine or southern

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* *Transactions*, Am. Soc. C. E., Vol. xlii, p. 288.

Mr. Reed.

pine ties, without any treatment, which had been laid by the speaker six years or seven years ago, are perfectly fit to be used again, and are thought to be good for five or six years' more service. Of course, the conditions are different from what they would be on a steam railroad, or on an elevated railroad. The ties are protected, more or less, by the paving of the streets, and are surrounded by the gases of various kinds under the street pavements of New York. Whether or not that is a preservative, the speaker is unable to say.

Eight or nine years ago, the speaker used 5 000 vulcanized ties in a surface railroad in the northern part of New York State. Five or six years later, owing to a change in the paving, some of these ties were dug up and were found to be so soft that they would not hold a spike, although they did not show much decay.

These ties were of short-leaf yellow pine, which may be one cause for the trouble. The wood was certainly softer in the beginning than the hard pine now being used in the streets of New York where tie construction is used.

The speaker is not able to say whether or not these soft ties would have hardened when dried out by exposure to the air. He did not try them, as he did not think they were worth saving. The whole tie was very soft, and there was not a great deal of moisture. The ties referred to were taken out at the intersection of Twenty-third Street and Ninth Avenue, where the ground is not low, but is fairly well drained, although the paving at that point had no concrete foundation, and more or less moisture could get through the pavement into the ground. The other ties taken out (long-leaf southern pine, not treated) were on South Street. They were protected more or less by a concrete foundation under a granite block pavement, with tar and gravel joints, but South Street is very wet a great deal of the time; in fact, it is flooded with water for a long time after a storm, so that the ground underneath is a good deal more moist than at Twenty-third Street and Ninth Avenue.

Mr. Tillson.

G. W. Tillson, M. Am. Soc. C. E.—The speaker was interested some time ago in looking up the methods and history of the preservation of timber, to see how long ago it was first taken up, and the many and curious experiments which were made. It is known that as far back as 1657 a German recommended the use of tar as a preservative of timber, and Baumeister, in 1798, was very much in favor of the use of salt. It was found that the timber used in ships engaged in the salt-carrying trade, as well as that used in the shoring up of salt mines, lasted a much longer time than timber under ordinary conditions, and the speaker was surprised this last summer, when visiting the wooden shipbuilding section of Maine, to find that they made use of that practice there now. The salt is distributed in great quantity among the timbers in the framework of the vessel, between the outer and the

Mr. Tillson. inner planking, and adds materially to the life of the vessel. This value of the salt is considered more on account of its hygroscopic than its antiseptic properties.

Boucherie, of whom the author speaks, had a system of treatment in the early part of the nineteenth century, which was certainly novel and unique. The timber to be treated was chosen while standing in the forest. Large cuts were made at the bottom of the trunk and a receptacle built around it; then the liquid proposed to be used was put in this receptacle and the respirative action of the tree—the suction—drew the liquid up into the trunk and branches and thus preserved it. Another method, practically the same, although somewhat different in detail, was to cut the tree down first and then insert the butt of the tree in a vat containing the preserving liquid. It is stated in Parnell's Applied Chemistry that a poplar tree 90 ft. high absorbed 10 cu. ft. of acetate of iron in six days, the liquid having a specific gravity of 1.056, and that it would go up as far as the leaves. If engineering is admitted to be the adaptation of the powers of Nature to the uses of man, this would seem to be a case of the pure science.

In Mr. Kummer's paper* some reference is made to the treatment of wood for pavements. The speaker thinks that Indianapolis, Ind., is the only city in this country in which wood as a paving material for an improved pavement is being considered seriously. Experiments have been conducted there for three or four years, and this year a large quantity of it has been laid. The timber is treated by the ordinary creosoting process, the specifications requiring 10 lbs. of oil per cubic foot of wood. The pavements treated by this method cost about $2.50 per yard. In London and other English cities which use wood as a pavement, soft wood, Baltic deal, is treated, while hard or Australian woods are untreated. Of course, the principle by which they determine whether they shall or shall not creosote the wood is practically the same as with railroad ties. If the traffic is such that the wood will wear out before it would naturally decay, it is not treated; but if the traffic is light, so that the wear will not be very much, but the life of the pavement be determined by its ability to resist the action of the weather, then the question of creosoting comes in, and when the relative lives of the creosoted and the uncreosoted blocks are known, and also the cost of the treatment, whether it shall or shall not be used is simply a question of mathematics, as in the case of ties.

Mr. Cohen. MENDES COHEN, Past-President, Am. Soc. C. E.—When this subject was under discussion before the Society some years ago, the speaker stated as the result of his experience with the Burnettizing process on the railways of the Lehigh Coal and Navigation Company, while under his charge, that the process was effective, not only in increasing the durability of the ordinary tie timber, but that, in a measure, it tended to lessen the original average cost of the ties by making available for such use some of the softer timber, greatly toughened by the treatment, which could not, otherwise, have been used in the track. Mr. Cohen.

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* "A Proposed Method for the Preservation of Timber," *Transactions*, Am. Soc. C. E., Vol. xliv, p. 181.

He also then stated that the use of the Burnettizing process was suspended on that work only because the location and arrangement of the yard and plant was not consistent with economical handling. Before its re-location was effected, the railway property passed into the control of another corporation, and the speaker had no further information in regard to it.

Samuel Whinery, M. Am. Soc. C. E.—From the speaker's observation in a number of cases, he thinks that a great deal more importance attaches to the proper selection of the wood to be treated than has often been devoted to the matter. In some of the work which he has observed, the timber was cut without much reference to whether it was long-leaf yellow pine or scrub pine. It was brought to the works in all conditions of seasoning, and he has no doubt, from the observations made since, as well as from what Mr. Chanute states in the paper, that the careful selection of the timber and its proper preparation by seasoning before it is treated has much to do with the success of the process. In the case of paving blocks, there can be no question that properly selected wooden blocks, properly creosoted, will give much better results in all cases where untreated blocks would fail by natural decay before they are worn out by the travel over them; but it is very doubtful whether creosoting adds anything to the ability of the blocks to withstand the abrasion of travel. Mr. Whinery.

From what one often sees in practice, it would seem that anything is considered good enough to creosote. That is, that almost any kind of wood, even if partly decayed, is all right if creosoted. The idea that creosoting is a cure for all the evils that wood is heir to is undoubtedly wrong. If great care were taken to properly select the timber, and to properly prepare it for the process, there would be fewer records of failure.

Those who have had experience in using yellow pine ties on southern railroads know very well that, in the first place, there are not many inspectors who can distinguish, when a tie is dressed and delivered on the road, whether it is of long-leaf yellow pine or bastard pine, that is, in appearance one merges so gradually into the other that it is sometimes difficult to decide. We know very well, though, that of a lot of ties put into a track at a given time, some will begin to fail in 4 years, more in 5 and many more in 6 years, and that some will last 10 years, and a few will last even 11 and 12 years. The conditions of use being practically the same, the difference in durability must be due to a variation in the quality of the timber.

Mr. Rowe. SAMUEL M. ROWE, M. Am. Soc. C. E. (by letter).—Mr. Chanute's paper, embodying, as it does, a fair epitome of European experience and knowledge up to the present time, is of much interest to those concerned in timber preservation in this country, and seems to deserve more than a passing notice

The following is a synopsis of the salient points to which the writer will revert, and, for the sake of brevity, and to avoid the necessity of referring directly to the subject in each individual case, he will take them up in the order given:

(*a*) Greater cost of creosoting than of Burnettizing.
(*b*) Life of treated ties in Europe as compared with this country.
(*c*) Selection of timber.
(*d*) Drainage of road bed.
(*e*) Thorough permeation of the timber by the preservative.
(*f*) Increasing the amount of chemicals injected.
(*g*) Minute care during all stages of treatment. (Impregnation.)
(*h*) Treatment of oak. (White oak.)
(*i*) Test of strength and purity of chemicals.
(*j*) Timber supply.

(*a*) In regard to the creosote process, Mr. Chanute's observations in Europe seem to confirm the correctness of the position taken by the writer and many others in this country, that, owing to the difficulty of procuring suitable oil, and from its large and continually increasing cost, the process is virtually ruled out in this country, except, perhaps, in special work required to protect timber against the teredo.

This is also true, in some degree, with the zinc-creosote process by Mr. Rutgers, of which process Mr. Chanute seems to think very highly.

(*b*) In regard to the life of treated ties in this country, the experience on the Atchison, Topeka and Santa Fé R. R. and the Southern Pacific R. R., after 12 to 15 years, seems to fix the mean at 10 to 12 years, where the zinc-tannin process was used.

In this connection, the writer's experience may be of value. The original mountain pine ties were laid on a portion of the Southern Division of the A. T. & S. F. R. R. in 1880, and by 1886 the right of way was strewn with removed ties, or rather, with masses of rotten wood, having but little semblance to the ties originally laid. There was then a standing order that removed ties should be piled and shipped to the division points for locomotive fuel. Finally, the accumulation became so great and its unfitness for fuel so obvious, that many huge bonfires were the result. From this experience with untreated pine ties, a life of 4½ years was all that could be deduced. Some of these ties failed in the third year, and the company was face to face with a serious problem. In July, 1885, the Las Vegas Timber Treating Works were installed, and have been in almost constant operation since, but no systematic count of treated ties removed was made until early in 1897, since which time the company has worked quite carefully to secure a record. Although this record is too limited as yet for definite estimate, it furnishes a basis for a statement (by the laws of averages) by which the probable mean life can be estimated. On the assumption that the mean life is 12 years, it is found that of the earlier treated ties, not anything like the numbers that should have perished have been removed, so that it is proper to assume that 12 years is too low. The writer is informed that very many ties laid in 1885 are still in the track, and he would not be surprised to find some still in at the end of the twentieth year. To settle this definitely, however, will require the record of the next 3 or 4 years. We have, nevertheless, sufficient to show the marked contrast between the untreated and the treated ties, and there are frequent acknowledgments from the management that the substitution of the treated ties has resulted in marked economy. It should be further remarked, that the condition of the track is now very much better than was possible when untreated ties were being used, and that the treated ties, when removed, are in much better condition than the untreated, having still considerable sound timber remaining, whereas the untreated ties when removed are entirely gone. Mr. Rowe.

There is no parallel by which to compare the results with those in Europe, except one case of pine in France, and in the case of Mr. Rutger's zinc-creosote, where the result as to life is somewhat better than is given here with the zinc-tannin process.

(*c*) The advisability of drawing high requirements as to the quality of the timber in this country is not clear, except merely for comparison with work in Europe where the specifications are severe, which is here of little consequence practically. The fact is, that the tie supply in this country has been and will continue to be drawn from inferior woods; and even with the oaks, only the inferior portion is being made into ties, while the select portions go to other purposes. This is true as to other and less durable timbers, not heretofore considered fit for ties; hence the railroads will continue to buy the cheaper grades. It is in consequence of these conditions that the soft and inferior woods, by the aid of treatment by which their lasting qualities are made greater than those of the best oak, will be sought. Thus is opened a much enlarged field of supply, together with a reduction in cost and a very marked reduction in the cost of maintenance.

Another point which may properly be noticed is the sawing of ties from large logs, which should make good ties on account of the superiority of the timber and its lasting qualities compared with the sap-pole tie made from the same kind of timber. The timber should last one-half longer at least, other conditions being equal. The

Mr. Rowe. practice now common is to cut the ties 6 x 8 ins., and 8 ft. long, containing $2\frac{2}{3}$ cu. ft., while the mean volume of the pole tie, upon which the number and distribution of ties under the rail has been founded in railroad practice, is more than 4 cu. ft. These sawed ties are so small that they do not form a sufficient support for the rail, unless the number is materially increased; and they are apt to fail, from rail wear or from insufficient body to hold the spikes, long before the timber decays. It would seem that a tie 7 x 9 ins., with a volume of $3\frac{1}{2}$ cu. ft., would be as small as should be made. Such a tie, properly treated, would last 15 years or more.

In connection with English timber preservation, Mr. Chanute mentions "Baltic redwood." In discussing these questions it would be well to state, for each kind of wood, the characteristics by which it might be judged. These characteristics have much to do with the lasting qualities, and, if some standard could be devised, for instance, the oak, heavy, close-grained, strong and lasting, the beech, walnut, etc., close, even grain, but not so strong or lasting, and lastly, the pines, etc., so as to enable those interested to judge somewhat as to their character, it would be a great aid in comparing results. Mountain pine, to which western railroads are obliged to resort, runs largely to open-grained timber, easily penetrated and taking the treatment readily if dry, yet it is an inferior timber, with many imperfections. Of course, some portions of the large, well-grown trees give sound, compact, well-matured fiber, and therefore, should be quite lasting, but taking all together, the timber treated in Europe, high priced, cut and shipped under severe specifications, forms hardly a fair parallel. The very fact that these A. T. & S. F. R. R. ties have been made to last 12 years, or anything like it, speaks well for the efficiency of the treatment and methods followed at Las Vegas.

(*d*) Mr. Chanute mentions, as one of the conditions favorable to the life of the tie, the thorough drainage of the road-bed.

In this country, in almost all cases, the treated ties are shipped directly from the works to the locality where needed, and are there racked, ready to be put in place. In the interval, they receive a certain, or rather, an uncertain, amount of drying, and are then put in track. In a dry climate this is not so important, but in a moist climate it is conceded that the ties should be quite dry before being placed. Taking this condition as requisite, the effect on the tie of exposure to the elements will be considered. The generally accepted theory of the capillary process of absorption of water when the wood comes in contact with it, is probably correct. The chloride in the treated tie, being readily soluble, is dissolved by the water, and carried with it as it penetrates the piece. By the contrary operation of surface evaporation in drying out, the chloride will be gradually

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dropped, and finally, such of it as reaches the surface of the wood, will be deposited on its surface, or in the soil in which the tie is bedded and there be lost. It is easy to see that this may result in loss and final wasting away of the antiseptic to a greater or less degree, depending upon the frequency of the exposure. Then, when drainage is imperfect and the tie lies in the water all the time, the absorption being continually from the bottom and the evaporation from the top, it is easy to see that the waste must be more rapid than when it is alternated, as by showers of rain.

In confirmation of this general theory, the Department of Agriculture has made some careful investigations on alkali soils, by which it is found that alkali sinks into the soil on free application of irrigating water, allowing cultivation of the soil, but when the irrigation ceases and the ground is exposed to extended drought, the alkali again rises and the land becomes sterile as before.

The alkali (sodium sulphate) existing in the soils and ground-waters of the western plains has the same characteristics as chloride of zinc, being only a little more readily soluble, and increases the specific gravity of the water. At Edgemont, S. Dak., the water used has nearly 125 grains of sodium sulphate per gallon, giving, at 60° Fahr., a hydrometric reading of 0.25° Beaumé, so that this correction has to be made in reading the strength of the chloride solution.

It would seem, too, that the effect of water on creosoted timber, while not so deleterious as on the chloride (as it only affects the lighter and less valuable parts of the oil), is still sufficient to demand attention. Creosote not being at all soluble, a different cause for its expulsion must be sought. It is well known that wood expands when exposed to dampness, the wood fiber absorbing the water and opening up, while the wood swells. The result is that the oils are, to some extent, squeezed out.

In this connection the writer has under examination samples of paving blocks treated by the "Creo-resin process," furnished by the kindness of City Engineer Erickson. These blocks seem to be well impregnated with creosote oil, reinforced by a quantity of resinous pitch, and they have every appearance of being an excellent paving material. These, with similar untreated blocks, were immersed in water on September 4th, 1900, and have now been in 60 days. At 30 days the absorption by the treated blocks was only about 33% of that of the untreated, the resinous pitch exuding but slightly; but at the end of 60 days the absorption of the treated blocks had gained considerably, as compared with those untreated, and a large amount of pitch had come to the surface, appearing in large globules adhering to the blocks. So marked was this action that it was deemed desirable to extend the experiment another month, and note further its extent.

Reverting to the original question of thorough drainage of the

Mr. Rowe. roadbed, it would seem unnecessary to insist on this in this advanced age of railroading, as such neglect is so destructive to the track as a whole and to the reputation of the roadmaster. It is easy to see that if the action just described takes place, it would be likely to soon exhaust any antiseptic that could be put into the timber.

(*e*) The most thorough permeation of the timber by the antiseptic is a fundamental part of the work, so far as the zinc-tannin or the Burnett process is concerned. The application of a stronger solution superficially will not make up for the lack of permeation, as it is not known that the chloride will diffuse in time. Steaming under pressure is the best and most effective means to secure through permeation, and it must be gauged or prolonged to meet the character and condition of the timber. Oversteaming sometimes will reduce the amount of absorption of the solution, but, on the other hand, the permeation will be more perfect. Thorough permeation by the steam can be best observed by noting the character and condition of the condensations blown from the retort from time to time. First will be observed the condensations caused by the steam coming into contact with the more or less cold charge; next, will follow a discharge of water tainted with the juices of the timber, increasing in its turbid and frothy condition as the steaming progresses, and then losing this character gradually and flowing off in the form of pure condensed steam or water. This last stage indicates that the steam has reached the heart of the timber, which is then in proper condition to receive the solution, whether creosote oil, chloride solution or whatever is used. From the quantity of this highly charged water thus thrown off, the impression is that the timber has been cleared largely of its natural juices and of fermentable matter inherent therein. The vacuum drawn at the termination of steaming, of course, will still further free it from any remnants of saps, but its chief function is to draw the air and vapors from the retort and prepare the timber for the introduction and absorption of the solution, which is let in while the vacuum is still on.

How absorption takes place when this point is reached, the following observations made at Las Vegas in 1885 will best show:

	Hewn ties.	Sawed ties.
First half-hour..............	0.42 per cent.	0.54 per cent.
Second half-hour	0.24 " "	0.31 " "
Third half-hour..............	0.16 " "	0.07 " "
Fourth half-hour.............	0.11 " "	0.04 " "
Fifth half-hour	0.07 " "	0.03 " "

(*f*) The question of the injection of liberal quantities of chemicals is of great interest just now, when managers are looking to reduction of cost. The chemicals form the most costly part of the treatment, and, while it must be insisted that enough be used to get the best re-

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sults, there is an extreme which cannot be passed without wastefulness. At the time the writer was in the a-b-c of this matter, he was instructed that $\frac{25}{100}$ of 1% of the weight of the timber was the minimum amount of chloride allowable. On this basis, a careful determination of the mean weight per cubic foot of the dry ties for treatment at Las Vegas was 31 lbs. or thereabout. One-quarter of 1% would be 0.075 lb. of pure chloride, or a little over 1 oz. per cubic foot of timber. In view of the statements in the preceding paragraph, it might seem to be enough. In any case, the mean absorption of the ties treated in 1885 was about ¼ lb. per cubic foot. The absorption of some of these ties probably did not exceed the minimum mentioned, and yet, these 1885 ties are being pointed to as eminently good. The strength of the chloride solution then used was 0.015, or 1½%, and the average absorption, compared to volume of timber, was about 30 per cent.

In approaching this question of quantity, the operation must be studied closely. A dry tie having a volume of 4 cu. ft. would weigh 125 lbs. A green, freshly cut tie of this volume, with all its sap, would weigh 187 lbs., having about 16 lbs. of sap per cubic foot, the sap presumably containing almost all the fermentable agents. As before noticed, a large proportion of the juices are expelled by the steaming and the vacuum, say 75%, leaving 4 lbs. of sap to be neutralized by 1 oz. of pure chloride, or a 1½% solution.

Mr. Chanute explains that by the rule referred to the amount was later found to be too low.

Attention is called to this, with the hope that some one who is favorably situated will take up this investigation, as any proposed increase in the cost of chemicals, in the face of the calls for cheaper work now being pressed, makes it very desirable that something definite and authoritative should be determined.

(*g*) In closing his valuable paper, Mr. Chanute says: "It cannot, however, be too strongly insisted upon that the work must be well and skillfully done, for, otherwise, the results are sure to be disappointing."

This is most heartily emphasized, and it follows that skillful operators must be employed. In Germany, as Mr. Chanute states, about the only successful and satisfactory work has been done by a private firm who makes it a business and conducts it on business principles, and an important part of whose assets consists of honest work. There is no doubt that any party operating in this country on the same principles can succeed. In either case, the skilled operator is the first requisite, and it is the same with any great railroad company that decides to do its own work. In Germany, it is said that the skilled operators can be counted on the fingers of one hand, and probably the same is true in this country. In the installation of a plant of this

Mr. Rowe. kind, a matter of the first moment is that an inexperienced and untrained operator should no more be put in control and direction than that a college student should be put in charge of one of the big steel plants. The proposed "operator" may have read every word written on the subject of timber preservation, and, if he has escaped the lunatic asylum, he has reached but the a-b-c of the matter, and must still have intelligent training through practical contact with the work. He must have the rules fixed by an experienced teacher and be made to apply them; and, above all, he should not allow himself to go out on any theorizing excursions, as all such are likely to prove disastrous, both to himself and his employers.

(*h*) The writer is pleased to note that oak (presumably something like our white oak) is not barred out from the woods treated in Europe Regarding the selection of tie timber, it seems to be axiomatic that "the better the timber, the better the tie it will make," regardless of treatment. Experience and reason show this, and if the life of an oak tie of the best quality can be prolonged but 2 years, it is economy to treat it. Taking the white oak tie as it runs, there is a strong probability of doubling its life. The objection that the oak will not absorb sufficient to do any good, is, in the light of experience, a mistake, and is illogical, when the nature of the process and its effect is understood.

(*i*) Mr. Chanute mentions the "constant testing of chemicals, as to strength, purity, etc.," in connection with the requirements in European practice. It is presumed that what is meant is tests which may be performed on the work during operation, where it is not always practicable, to call in the aid of the chemist. It is necessary that the operator be able to determine quickly, approximately at least, the strength of the solution, whether chloride, tannin or glue, without the elaborate processes of the chemist, as, in the course of the operations, these solutions are constantly varying. We have been indebted to Mr. Chanute in this respect, and would be glad to have him give, at length, such facts as he has gathered, couching them in such terms as would be within the comprehension of any intelligent operator. Such information would be valuable indeed.

(*j*) Mr. Chanute's remark in relation to the exhaustion of the timber supply introduces a theme, the importance of which, in this country especially, should be impressed at all times. In the last 30 years we have seen such destruction of our great forests as seems appalling. With the exception of a small territory in northern Maine, some small areas in the South and the region of the extreme Northwest, the forests have been invaded and the most valuable timbers have been more or less cut away. In many cases, shameful waste and destructive fires aid in the devastation. The tie renewals amount to nearly 70 000 000 annually, to-day, compared with 4 000 000 required in France, and the ratio will increase as the mileage increases. Mr. Rowe. Although our forests seem boundless, they are not so, relatively; and, at the present rate of consumption, the scarcity of cross-ties, now beginning to be felt, will soon be serious. A parallel to this can be cited, quicker in its consummation, but by no means so far reaching and disastrous—that of the bison, thirty years ago teeming in millions over the western plains, but now hardly a representative remaining. This is a lesson to ponder.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

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PAPERS AND DISCUSSIONS.

NOTE.--This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

CANALS FROM THE LAKES TO NEW YORK.

Discussion.*

By Messrs. THOMAS CURTIS CLARKE, EDWARD P. NORTH, THOMAS MONRO, FRANK A. HINDS, ELNATHAN SWEET, W. HENRY HUNTER, THEODOR G. HOECH, ALFRED NOBLE and LEWIS M. HAUPT.

Mr. Clarke. THOMAS CURTIS CLARKE, Past-President, Am. Soc. C. E.—All are agreed upon the necessity of some water communication, between Lake Erie and New York, better than that which now exists, as it has shown its incapacity.

Some advocate a 12-ft. canal to pass barges which they hope could navigate the Lakes and avoid transhipment. The speaker formerly favored this plan, as he then believed that the cost of a deeper canal would be prohibitory.

Mr. Wisner has shown that the cost of a canal 21 ft. deep, from Lake Erie to New York, through the Mohawk Valley, would be $200 000 000, and by way of the St. Lawrence and Lake Champlain $15 000 000 less.

He considers that if the canal were made deeper, the greater interest on its cost and its depreciation would exceed the saving in transportation.

He shows that a 21-ft. canal gives economy of transportation even after adding the charges for interest and depreciation. This is the first time that this statement has been positively made.

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* Continued from November, 1900, *Proceedings*. See October, 1900, *Proceedings*, for papers on this subject by Messrs. Joseph Mayer and George Y. Wisner, Members, Am. Soc. C. E.

Mr. Clarke.

The writer agrees with Mr. Wisner in believing that the sum of $200 000 000 is not prohibitory—that a canal for the largest ocean vessels will never be made on account of its enormous cost—and that his figures of cost of transportation are substantially correct.

His reasons are briefly these: Experience has shown that a canal, requiring transhipment of freight at each end, cannot compete with all-rail, or rail and lake navigation.

A canal 12 ft. deep would probably pass tows of barges large enough to navigate the Lakes. It would, however, require transhipment at sea ports, and could not compete in economy with a canal large enough to pass Lake and ocean vessels, if the cost of such a canal did not stand in the way.

In the speaker's opinion, Mr. Wisner has proved that its cost would not be great enough to overbalance its economy of transportation, if made 21 ft. deep.

Can steamers, fit to navigate the Lakes and pass this canal, navigate the ocean economically ?

The answer is, that such vessels, or even smaller ones, have done so for many years. What is to prevent a tow of large schooners with five or six masts and having auxiliary power, from passing through such a canal.

It is perfectly true that larger vessels, such as those running between New York and European ports, would show greater economy on the ocean, but not in artificial waterways.

It is believed that the Champlain Route would be less opposed by vested interests than the Mohawk Route, as the destruction of property would be much less.

The estimates of damages are:

By Mohawk Route	$14 039 000
" Champlain Route	6 259 000

Private capital probably would not invest in either undertaking; nor would the State of New York do so without an entire change of its present policy, which seems unlikely.

The United States—the richest power in the world—can easily afford to construct this line of communication. It is necessary to first get a congressional majority in its favor. Some years ago that would have been impossible. Now it seems to be possible.

The City of Chicago, after having expended $34 000 000 on her drainage canal, 24 ft. deep and large enough for Lake vessels, has offered it to the General Government on condition that the same scale of navigation shall be continued to the Mississippi River.

L. E. Cooley, M. Am. Soc. C. E., in a paper presented to The Western Society of Engineers, estimates the cost of a 20-ft. waterway from Chicago to St. Louis, 360 miles long, at not over $140 000 000.

The problem of extending the same depth from St. Louis to the mouth of the Mississippi, some 1 100 to 1 200 miles, is as yet unsolved.

Mr. Clarke. There is much to be said in favor of the plan advanced by James A. Seddon, M. Am. Soc. C. E. (described in a paper presented to The Western Society of Engineers), for preventing floods and maintaining depth of water in the Lower Mississippi by the construction of a reservoir system formed in the bottom lands between the river and the bluffs. These reservoirs would retain flood waters, and let them out during seasons of low water.

Thorough surveys should be made by the United States Government to ascertain the facts. Mr. Seddon's estimate—$50 000 000—seems to be low.

The interesting fact is, that a union of interests between the western, southwestern and eastern States can now possibly be brought about to construct this great system of internal navigation from New York to Chicago and thence *via* New Orleans to the Gulf of Mexico.

The proposed Isthmian Canal is a vital part of this scheme. If that canal alone were built it would give only the Atlantic cities and New Orleans a short line to the Pacific, and the Pacific cities one to the Atlantic. If the entire scheme were carried out, it would take in the whole central part of the United States.

The total cost, including the Isthmian Canal, would probably not exceed $600 000 000. Some years ago that sum would have shocked careful financiers. But now that United States bonds can be placed bearing 2%, it means a yearly tax of $12 000 000, or about 16 cents per head of the population.

The United States has now become a World power, exporting its agricultural and manufactured products and coal, iron and copper to all countries. Its imports and exports have increased nearly 50% during the last six years, or from $1 710 000 000 to $2 427 000 000. The exports alone have risen from $921 000 000 to nearly $1 500 000 000. Such an increase has never before been seen in the history of the world.

If we wish to preserve this enormous trade, in the face of the sharper competition which must inevitably soon take place, we must give it the least expensive routes of transportation. The railways will take care of it during the season of closed navigation; during the open months, such a scheme as has been outlined is necessary to enable all of our States to reach countries on both the Atlantic and Pacific Oceans by the shortest and least expensive routes.

Nature has already done much to create this vast internal navigation, and we would be lacking in energy if we did not apply from our surplus revenues the sum necessary to complete what Nature has begun.

When this is done, the seat of the world's commercial empire will be transferred from Europe to that part of the United States where grain, coal, iron and copper lie side by side, controlled by the most energetic and inventive people that the world has ever seen.

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EDWARD P. NORTH, M. Am. Soc. C. E.—It is a matter for congratulation that members of this Society turn from considering expert measurements of quantities to questions involving large additions to the service and convenience of mankind, and essay to direct those large sources of power in Nature—public opinion and the service of capital—to increasing the facilities for transportation and decreasing the cost of distribution over large areas of this country, as in the two admirable papers before us.

It is also pleasing to notice that both authors, though proceeding by different routes, reach substantially the same conclusions, viz., that with near-by railroad trains carrying 2 400 tons and a 14-ft. canal parallel to it, a 10-ft. canal may influence freight charges, but can neither control such charges, direct the course of commerce, nor prevent the present system of discriminating charges against production and consumption in this country generally and the commerce and industries of the City of New York in particular. And any money invested in procuring such inadequate transportation facilities must fail to return a normal reward.

In view, however, of the rapidly expanding trade of the Great Lakes, the determination to make their governing depth 24 ft. and the probability of a waterway of large capacity connecting the Lakes with the Gulf of Mexico, doubts may be felt as to the advisability of limiting to 21 ft. the depth of what should be one of the largest channels of distribution, or as to imposing tolls on a traffic which it is wished to develop. The toll proposed is not large, either absolutely or in relation to the probable value of the goods to be transported, 2 to 2½% on the value of the goods passing the Soo, and will not operate as does the yearly abstraction of $15 000 000 or $16 000 000 from the resources of those trading through the Suez Canal; a most onerous impost that must in part account for a tonnage of 8 000 000 or 9 000 000 sufficing for the wants, or capacity, of 1 100 000 000 people, while the 40 000 000 served by our lake carriers use 40 000 000 tons.

But to some extent any toll decreases traffic, principally by preventing or hindering the production and marketing of low-valued commodities, also by diverting travel or freights to other routes. The marked differences in the development of freight and passenger traffics in this country on the one hand, and in European countries on the other, seem to show the effect of high and low charges on the volume of traffic. Poor's Manual gives very full statistics of the traffic on all our railroads, commencing with 1882. From these data Table No. 1 has been made, excepting in the columns as to population, which for 1899 has been taken as 75 500 000.

Here the average passenger rate is persistently high; higher, it is thought, than in other countries. The freight rate, which in 1882 was lower than in any other country and about half the passenger-mile

Mr. North. rate, is now, according to Mulhall, less than half the freight rates in any European country, and 36.3% of the passenger rate. As a consequence, the passenger mileage has increased 93.3%, while the ton mileage has increased 223.1 per cent. In European countries, on the other hand, there has been conservatism in the matter of freight rates; but, through zone tariffs, improvements in the comforts of third-class carriages, etc., average passenger rates have been materially reduced, and though there is no knowledge of such full statistics as those for American roads it is thought safe to say that the passenger traffic has had a growth approximating to that of American freights, while the freight traffic has developed on lines somewhat parallel with the development of passenger movement on American railroads.

TABLE No. 1.

Year.	Miles operated.	Rate per Mile in Cents.		Miles transported 1 = 1 000 000.		Gross Receipts. 1 = 1 000.		Transported per Mile Operated.		Transported per Inhabitant. Miles.	
		Passengers.	Freight.	Passengers.	Freight.	Passengers.	Freight.	Passengers.	Freight.	Passengers.	Freight.
1882....	95 725	2 447	1 236	7 688	39 302	188 137	485 778	80 313	410 572	146	748
1899....	186 280	2 002	0 726	14 860	126 992	397 560	922 436	79 770	681 725	197	1 682
Inc. or Dec..	+94.6	−18.2	−41.2	+93.3	+223.1	+101.7	+89.9	−0.007	+66.0	+34.9	+124.9

It may be claimed that the figures given in Table No. 1 do not fairly present the relations existing between our freight and passenger traffics, as no account is taken of the influence of electric railways paralleling our railroads, and the decrease in passenger traffic since 1894. But the effort of continued conservatism in upholding passenger rates, after a full recognition of the fact that a reduction would develop such large accessions to the traffic as to require additional accommodations, is exactly the point for which attention is solicited. By this general conservatism, which is well typified by the story of the New England directorate which refused its commuters' request for an additional train with the assertion that in a short time they would crowd it as uncomfortably as the trains they then had, the railroads of this country possessing a right of way with much if not all of the necessary grading and track laying done, and its passenger department organized, have forced their patrons into the expense of new organizations, new rights of way, grading and track, and experiments with an undeveloped motive power, that the circulation of passengers on

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lines parallel to their tracks might not be unduly curtailed by high rates of passage. This does not, it is submitted, vitiate the deductions apparent from the table. Nor does the fact that the electric roads are likely to add materially to the convenience and wealth of the country throw doubt on the inference that if passenger fares had been reduced as freight rates have, the passenger mileage would have kept pace with the freight mileage.

The comprehensive and valuable system of statistics inaugurated at the Soo in 1887 and continued by the United States Engineers since then, statistics which have done so much to strip the value from those conservative predictions which vested interests will always call expert and authoritative, show that, for the five years ending with 1891, 37 352 066 tons of freight were carried for $45 913 715, or $1.23 per ton; and for the five years ending with 1899, 96 774 880 tons of freight were carried for $77 065 077, or $0.796 per ton. Here a fall of one-third, in the cost of transportation, was paralleled by an increase of nearly two and two-thirds times, in the freight transported. Or, to use another standard of measurement: During the first period mentioned, the freight charges on cargoes valued at $12.73 per ton were 9.66% of such values; and during the last on cargoes valued at $11.23 per ton, the freight charges were only 7.09 per cent. The average hauls were, for the first period 806 miles, and for the second 835 miles.

A case somewhat analogous to the foregoing was mentioned by Mr. Vreeland, President of the Metropolitan Surface Railway of New York City: On the Madison Avenue line the time of a trip with horses was about 1½ hours, and the road carried 17 000 000 passengers. On the introduction of electricity the time was shortened to about 1 hour and the road carried 50 000 000 passengers. In the first case a reduction of one-third in the cost of service was accompanied by an increase of freight carried by two and two-thirds times. In the other, a reduction of one-third in time without reduction in cost of passage was accompanied by an equal increase in the number of passengers carried.

Unless the above-quoted figures are inappropriate, they show that if we are to have the full encouragement to production and consumption due to a waterway convenient for the exchanges between the 40 000 000 tons of traffic on the Great Lakes and the 79 000 000 of entrances and clearances at the Port of New York, as now estimated, the traffic should pass through ample channels unvexed by toll gates as well as transfer charges. But if the prospect of tolls is necessary to induce the construction of the canal, they should be imposed, as there would still be left a large margin of profit in comparison with present rates.

It may be well at this place to recapitulate the work done and the projects brought forward for cheapening transportation between the Great Lakes and the harbor of New York. Commenced in 1817 and

Mr. North. completed in 1825 with a cross-section of 136 sq. ft., the Erie Canal added so much to the wealth of the State that it was determined in 1835 to enlarge its cross-section to 429 ft., an increase of 215 per cent. This enlargement was not legally completed until 1862, although the increased cross-section was available for traffic some years before that date. The law authorizing this enlargement prescribed a nearly rigorous adherence to the original location. In 1897, work was commenced on a further enlargement to 562 ft., an increase of 23 per cent. This was to be accomplished on the plan advised by Horatio Seymour, M. Am. Soc. C. E., then State Engineer, by deepening the prism from 7 to 9 ft. An appropriation of $9 000 000 was made for this purpose, no improvement on the original location being contemplated. In the summer of 1898, the appropriation being exhausted, work was suspended, the State Engineer estimating that it would cost $4 800 000 to finish the improvement of the Erie, Oswego and Champlain Canals. Work has not been resumed.

Tolls, that in their aggregate are greater than all the expenditures on the canals of the State up to the present time, excepting for interest, were collected on local and through freights until 1882.

In 1884, Elnathan Sweet, M. Am. Soc. C. E., State Engineer of New York, read a paper before this Society advocating the enlargement and relocation of the Erie Canal so that it should pass the largest lake vessels and be fed for its entire length from Lake Erie.

In conformity with a law of March 2d, 1895, a mixed commission, consisting of three citizens of the United States and three of Canada, reported in January, 1897, recommending, as was thought probable, surveys of two routes, both through Lake Ontario, one *via* the St. Lawrence and Lake Champlain, the other through Oneida Lake and the Mohawk Valley.

An appropriation bill of 1897 provided for the appointment of a board of three engineers known as the Board of Engineers on Deep Waterways, to make surveys, examinations and estimates for a deep waterway between the Great Lakes and the Atlantic tide-waters. This board was confined in its power to making surveys, etc., on the routes recommended by the Deep Waterways Commission, which reported in January of that year. This report has not yet been given to the public, but some of its conclusions are given in the paper by Mr. Wisner, who was a member of this board.

In 1897, under requirement of the River and Harbor Act of 1896, directing the Secretary of War "to cause to be made accurate examinations and estimates of cost of construction of a ship canal by the most practicable route, wholly within the United States, from the Great Lakes to the navigable waters of the Hudson River, of sufficient capacity to transport the tonnage of the Lakes to the sea," Major Thomas W. Symons, M. Am. Soc. C. E., reported on what he calls "the broader view of the subject," recommending a ship canal through Lake Ontario, water which is owned in common by this country and Great Britain. That on completion of the Seymour plan, and the removal of restrictions as to capital of companies operating on the canal, the Erie Canal would "give commercial advantages practically equal to the commercial advantages which would be given by a ship canal." That a barge canal with a cross-section of 1 208 sq. ft., "will enable freight to be transported between the East and West at a lower rate than could a ship canal (cross-section 4 176 ft.) navigated by large lake or ocean vessels." Mr. North.

Actuated, possibly, by the political uses made of the failure of a popular estimate of cost to complete the enlargement provided for in "the $9 000 000 act," the Governor of this State asked five eminent engineers and business men in connection with the State Engineer and State Superintendent of Public Works to form themselves into a "Committee on the Canals of New York State." This committee reported in January, 1900: That the canals should not be abandoned.

"That the project of a ship canal to enable vessels to pass from the Upper Lakes to New York City (or beyond) without breaking bulk is a proper consideration for the Federal Government, but not by the State of New York."

They also recommended a modification of Major Symons' barge canal, cutting down the maximum size of the boat usable from 200 × 30 × 10 ft. to 150 × 25 × 10 ft., thus reducing the capacity from 1 500 to 1 000 tons. This, by some unexplained mistake, is characterized as enlarging the waterway of the State of New York to its "utmost limit."

In the spirit of this report, a law appropriating $200 000 for a survey for a canal of the recommended size was passed in the spring of 1900, limiting the survey to "the present route of said canal," excepting some minor changes between Buffalo and Syracuse. This estimate is expected in January, 1901.

Lastly, "The New York Commerce Commission," consisting of five eminent citizens appointed in 1898, made a report in January, 1900, setting forth, among other conclusions:

"The decline in New York's commerce has been steady and continuous for many years; it has been more pronounced during recent years, and has now reached serious proportions in actual loss of exports."

"The loss to New York is due in great measure to a discrimination against New York in railroad rates imposed by an agreement, known as the differential agreement, between the trunk-line railroads of the American Atlantic sea ports, including the New York railroads."

"The differential rate applies, not only on products destined for export, but also destined for local consumption by the people of New York City."

"The State has it within its power, through an adequate improvement of the Erie Canal, not only to apply the remedy that will secure

Mr. North. it against further loss of its commerce, but will secure to it, as well, the restoration of that which has already been diverted."

The commission recommended the completion of the current enlargement, with a cross-section of 562 sq. ft , as adequate, acquiring additional terminal grounds and piers, and that certain laws be amended, particularly as to elevating grain.

This arrangement between the trunk lines reaching the Atlantic seaboard, giving differential rates on grain, both for domestic consumption and for export, is, in the aggregate, a serious injury to our farmers. The cheapest route for export grain *via* Atlantic ports is through New York, but, in favor of other roads and other cities, grain for New York has been for years penalized with a differential that amounted to 1.8 cents per bushel on wheat and 1.68 cents on corn; this has been lately reduced to 0.9 cent. During the five years ending with 1899, the average of the average rates charged on wheat, Chicago to Buffalo, as returned by the Merchants' Exchange of Buffalo, has been 1.82 cents.

Of course, it is perfectly competent for a committee of the New York Chamber of Commerce "to look with complacency, if not with actual pleasure" on the consequent diversion of grain exports to other ports. But is the man who grows the grain, which is burdened in any case with a relatively high cost of transportation, to look with any approximation to pleasure on a practice which puts an additional charge on his produce? As the committee says: "An adequate improvement of the Erie Canal," will apply the remedy. Their opinion, however, as to what is adequate, is even more restricted than that of the Committee on Canals of New York State.

It will be noticed that though sixteen sessions of the State Legislature have been held since Mr. Sweet read his able paper before this Society, advocating a radical enlargement of the Erie Canal, and two commissions have been appointed by as many presidents, some influence has seen to it that no survey has been made for a ship canal which would not be of greater use to Canada than to the United States. And it is possible to assert that a route through the richest and at one time the most prosperous section of this State "is not available for a ship canal," although no one can show any reason that on a judicious location a canal of large cross-section should cost more per mile between Buffalo and Oneida Lake than between that lake and the Hudson River.

Agreeing fully with Mr. Wisner that: "The dimensions which should be given to a waterway between the Lakes and the Atlantic depends upon the economic depth which can be obtained in the water routes to be connected," and accepting his estimate that the interest and fixed charges for an increased depth in the Lakes from 21 to 30 ft. would amount to an annual charge of $2 205 000, or 5.51 cents per ton on the

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traffic now passing Detroit, but taking exception to his declaration: "The actual saving in the cost of transportation on the Lakes by using deeper draft vessels is only about one-half the above estimated fixed charges," and differing from the deduction, "the interest and maintenance account will exceed any expected returns from lower transportation rates;" reference is made to the previously mentioned valuable statistics of the traffic at the Soo.

Although, as set forth in the Report of the Committee on Canals of New York State, previously referred to, the railroads were able to partially starve the Lake marine when there was a depth of only 11½ ft. on the miter sills of the locks at the Soo; the traffic through that waterway since the opening of the Weitzel, or 16-ft., lock in 1881, has been phenomenal. Opened in 1855 to a traffic of 106 296 tons, its traffic for 1881 was only 2 092 757 tons, but in 1895, the year the Canadian, or 20-ft., lock was opened, it had increased to 16 806 781 tons. In 1899, 21 956 347 net registered tons of shipping passed through the locks at the Soo, carrying 25 255 816 net tons of freight valued at $281 364 750. This freight was carried an average distance of 827 miles for $21 959 707, or at the rate of 1.05 mills per ton-mile, which is about 13% higher than the average cost for the three preceding years.

During the thirteen years for which we have returns covering the tons and value of freight, the distance carried and the cost of carriage, as well as the registered tonnage, the cost per ton-mile has decreased from 2.30 mills in 1887, when 5 494 649 tons were carried, to 1.05 mills in 1899, when 25 255 810 tons were carried. This is a decrease concurrent with the deepening of the Lake channels, and largely dependent on such deepening, and justifies the prediction the president of the Great Northern Railroad made while discussing the project of General O. M. Poe, M. Am. Soc. C. E., for a 21-ft. channel: that it would cut the Lake freight rates in two.

Mr. Wisner estimates the annual charge to the 40 000 000 tons passing through the Detroit River, due to deepening the Lake channels and harbors to 30 ft. as 5.51 cents per ton. If the length of haul by Detroit is equal to that through the Soo, 827 miles, the cost of deepening the Lake channels and harbors will be 0.076 mill per ton-mile. This would set the cost of transportation back to about the average of 1892 and 1893, if there was neither reduction in freight charges due to the larger channels nor increased production of freight to be transported. Neither of these suppositions is possible. The increased charge of 5.51 cents per ton would be divided by 80 000 000 within a few years after the deepening was effected, and while the larger carriers might not again cut freight rates in two, they could be expected to cut off about one-third of the present rates, leaving an average freight rate of 0.6 mill per ton-mile. This does not seem an unprofit-

Mr. North. able rate, in view of the volume and steadiness of the traffic and the average sea rates.

The assumption, that the traffic passing Detroit soon after, if not with, the earliest possible completion of 30-ft. channels and harbors will be 80 000 000 tons, is not thought too large for realization, as the traffic for some time, as shown by Mr. Mayer, has been doubling every six years, and the Chief of Engineers is reporting to Congress that prompt action in doubling the capacity of the St. Clair Flats Canal is necessary and important to the safety and convenience of the vast commerce of the Great Lakes. And deepening the channel to 23 ft. has already been commenced in the St. Mary's River.

Proposals have been made that the Erie Canal should be given to some railroad as a right of way, and numerous other schemes have been proposed like "the $9 000 000 plan," to impose a general hardship to the financial advantage of a few transhippers at Buffalo and New York. And lastly, we have the project to be submitted to the next Legislature of New York State to abrogate the necessity of transhipment at Buffalo by imposing a high rate of freight on the Lakes. The possibility of this perspective, however, has doubt cast upon it by the vociferous demands of "the friends of the canal," that large expenditures shall be made at both the Lake and Atlantic termini, that freight may be transferred more conveniently. All of these plans oppose the interests of both producers and consumers.

It is to the advantage of the City of New York and the New Jersey cities on the bay that this improvement should be so ample and commodious that no better or cheaper route between the interior of the country and the seaboard can be reasonably expected.

It is to the advantage of the State of New York that the canal should pass through the State and should be so large that the factory sites along its banks may have all the facilities for manufacturing offered by low freight rates, without transhipment, that the cities on the Lake front now have.

It is to the advantage of those living in the country to the west of this canal that it should be so located as to build up centers of production and consumption as near to them as practicable, and that its capacity for speedy and economic traffic should give the greatest possible encouragement to marketing those low-cost products which cannot stand railroad charges; as well as reducing the cost of all freight transportation, that the producer and consumer may have more to divide between them.

It is also to the advantage of the whole country that many waterways should be constructed or developed, that their control over railroad freight rates, as described twenty years ago by the late Albert Fink, Past-President of this Society, may be maintained and increased.

It is fortunate that the Hudson River carries a depth of 30 ft.,

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excepting at a few unimportant points, nearly to Coxsackie. (From there to Troy the State and General governments have increased the depth from 4 to nominally 12 ft.) This leaves only about 375 miles out of approximately 1 500 to be improved. With an economic depth of 30 ft. obtained in the Great Lakes, there seems to be no doubt that the channels connecting their commerce with our cities on the Atlantic coast and with the water front of the whole world should have an equal depth.

As no survey has been made for a ship canal between Lockport and Syracuse, an approximate estimate of cost may be made by adding 50% to the estimate of the Board of Engineers on Deep Waterways for the low-level, Oswego-Mohawk 30-ft. plan from Duluth to New York, given on page 995, viz., $317 284 348, as covering the increased cost of building the canal wholly within the United States, and a further addition of $36 000 000, the estimated cost of improving the Lake harbors. The aggregate, $512 000 000, at 3% interest, and 0.5% maintenance, would give an annual charge of $17 920 000. This sum would be directly repaid to the country by a saving of 0.27 mill per ton-mile on 80 000 000 tons carried an average distance of 827 miles.

The sum of 0.27 mill per ton-mile necessary to be saved on the estimated Lake traffic, when the channels from Duluth to New York are deepened to 30 ft., to directly recoup the country for the total expenditure would be reduced by the additional haul of 500 miles on all freight either destined to or originating in the Port of New York or beyond it. There would also be a further reduction due to eliminating the cost of transhipment at Buffalo, which Major Symons puts in his report as 27.1 cents per ton for package freight. These direct savings can be partly estimated, but the indirect saving due to the absence of delay and damage inseparable from transhipment cannot be computed with accuracy.

In estimating the amount of traffic attracted to a 30-ft. canal of sufficient cross-section, notice should be taken of the facts that there is no other people able to employ a ton-mileage equal to ours. The traffic passing Detroit is larger than any other water-borne traffic through one channel and is growing rapidly. The entrances and clearances at the Port of New York are more than twice those of any other seaboard port.

The traffic of this port has for some time been estimated at 70 000 000 tons. E. L. Corthell, M. Am. Soc. C. E., after careful research, preparatory to presenting a paper, "The Harbors of the World," to the VIIIth Congress on Navigation, held at Paris this year, states that the total entrances and clearances at this port are 79 544 653 tons. This tonnage he divides as follows:

In the interior trade	25 093 000 tons.
" coastwise	39 250 000 "
" foreign*	15 201 653 "

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* A writer in the *Forum*, December, 1900, states that the total entrances and clearances at the ports of the United Kingdom for 1899 were 209 348 081 tons. Of this, 97 782 887 tons were entered and cleared in the foreign trade.

Mr. North. As a matter of comparison, the entrances and clearances are:

For Liverpool	25 093 000 tons.
" London	30 215 000 "

It will be noticed that less than 20% of the tonnage of this port is engaged in foreign trade, and the aggregate tonnage of Liverpool and London, foreign and domestic, is 16% less than the domestic tonnage of this port.

Some nine years ago a board of engineer officers on the improvement of the Hudson River reported that the traffic of this stream was 18 500 000 tons, 3 500 000 of which were contributed by the State canals. Although it may seem incredible, it is a fact that many of the best thinkers to be found in the City of New York oppose materially increasing this contribution of the canals to the tonnage of their port, on the plea that the grain-handlers here and in Buffalo will be deprived of their opportunity to penalize production in the Northwest by exorbitant transfer charges on grain for export.

The population and wealth of the Port of New York is not dependent on its exports. Its unique natural position, making it the largest "port of call" in the world, is due to its having two large waterways back of it, viz., the Hudson and East Rivers. Adding to its natural advantages, the construction of the Erie Canal forced all railroad terminals to concentrate here, making its position the best in the world for manufacturing; for here raw products for manufacture can be assembled, and, the finished materials distributed to consumers at less cost than elsewhere, and, both in value of merchandise produced and in amount of wages paid, it is peerless. The present census will probably show that the wages paid in manufacturing industries in the cities and towns on the Bay of New York are nearly equal to the value of exports from the Port, and provision for traffic through the proposed canal that neglects the demand of New York and the cities ancillary to it on the Atlantic coast will fail in economic value, not only to the Atlantic front of our country, but to the interior.

No estimate of the freight entering and leaving the canal should neglect the manufacturing potentialities presented by the banks of the proposed waterway, which for nearly its whole length would offer factory sites with water and rail communication. The present status of manufacturing enterprises in the canal towns and cities is pathetic. From the inception of work on the Erie Canal until forty or fifty years ago this region offered higher rewards to ambition than any other locality, enjoying the cheapest and most convenient transportation facilities. Since the Erie Canal lost its pre-eminence as a carrier, through the development of railroads, while it remained unimproved, and rates in discrimination against short hauls have been imposed, the advantages offered by cheap transportation to other localities have worked injury to the interests of the center of the State.

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This fact has been recognized as to agricultural lands for some time. The twelfth census shows that in seven cities of 25 000 or more inhabitants in the center of the State, viz., Troy, Albany, Schenectady, Utica, Syracuse, Rochester and Auburn, all the cities of that class in the interior of the State, the rate of increase since 1880 has not been quite 52%, one city showing an absolute loss. The City of New York, with the dependent cities in this class, Jersey City, Newark, etc., show a gain of 81%; while the twelve cities on the Great Lakes, which have over 25 000 each, show a gain for the twenty years of 168.5 per cent. So low have our canal towns fallen in the estimation of some that they regard any attempt to relight the fires in their abandoned factories, or rebuild their ruined smelting furnaces as an attack on some inexorable law.

It is not proposed at this time to labor with the education of those who have been taught that production at one locality is always at the expense of another, and that the relative, to absolute, decline in value and population of the country along the line of the Erie Canal has aided the development of either the City of New York or the cities on the Great Lakes, but simply to assert the conviction that if the center of this State had continued the rate of development attained in the early canal period, both the lake front cities and New York would offer even higher prizes to ambition than under present conditions.

About two-thirds of the coal produced in Pennsylvania is mined east of the line of equal distances between Cleveland and the head of Seneca Lake. This should give shipping ports at the heads of Cayuga and Seneca Lakes the control of the anthracite trade of the upper Lakes, the control of all coal shipments to Lake Ontario and the upper St. Lawrence, and allow these ports to mediate effectively in the coal trade of the Atlantic coast.

The important influence of this proximity of coal on the manufacturing potentiality of this State, when combined with cheap and ample transportation, and particularly to that portion of the State which has been so carefully excluded from all plans for a ship canal cannot easily be overestimated. Over 50% of the tonnage on the canal at present is local, and under improved conditions it is possible, if not probable, that the same proportion of any traffic will be stopped either for consumption or to be reshipped with advanced value from manufacture.

At a deep waterways convention it was asserted by the President of the Lake Carriers' Association that two-thirds of the freight passing Detroit was on its way to be advanced in value by manufacture. If we can expect 80 000 000 tons to pass Detroit by the time Lake channels and the Erie Canal could be deepened to 30 ft., and that the tendency to advanced manufacture on the Lakes is offset by the

Mr. North. increased production of low-value goods due to cheaper freight rates, the average value per ton remaining as in the past, $11.14, the aggregate value transported will be $891 000 000. So moderate an assumption as that the two-thirds to be manufactured would be doubled in value by that process gives an ultimate value of $1 188 000 000 for the portion under consideration. If 65% of the increased value went to labor, it would employ 772 000 men at $500 a year; this would, as usually computed, support a population of over 3 500 000.

If one-third of the advance in value to Lake freightage by manufacture was given along the canal and in the City of New York, an addition of 1 200 000, or 17% to the population of the State would ensue, and to that extent would increase the local markets of our farmers. As the average capital of the inhabitants of this State will probably be shown by the present census to equal $1 250, such an addition to our population would increase the wealth of the State by $1 500 000 000. If the foregoing figures are approximately correct, the opinion that a ship canal should not "receive any serious consideration from the State of New York" might be sufficiently revised to permit further examination of the subject.

It is difficult to make an estimate that will be satisfactory to all, covering the proportion of Lake commerce which will enter a canal of sufficient cross-section: to be retained for consumption or manufacture in the State of New York, to be distributed to points in Pennsylvania and Lower Canada, or along the Atlantic coast, and to be exported. The City of New York and its environs could easily furnish capital and labor to absorb any possible increase of raw material offered for manufacture. The superior advantages presented by both banks of the enlarged canal from Buffalo to Albany would possibly give it a larger percentage of the total traffic than the present canal does, viz., 53 per cent. And the fact that 80% of the entrances and clearances at the port of New York are in the domestic trade, may justify an expectation that about half of the Lake freightage would enter or pass through the canal.

Although all sorts of statements have been made asserting the unsuitableness of vessels with a draft of 8 ft. and more, even in deepened lake channels, no one is known to have had the temerity to put a limit on the growth of the Lake traffic, and it would evidently be unwise to construct a canal too small to carry a traffic of less than 40 000 000 tons with the economy dependent on speed and convenience. An approximate estimate of the cost of such a canal, without reference to deepening the Lake channels, may be made by subtracting Mr. Wisner's $27 000 000, the cost of deepening the Lake channels, from the before-used $317 284 348, and adding 50% for building the canal through the United States. At 3% interest and 0.5% maintenance, the annual charge would be, say, $15 250 000.

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If a probable ton-mile rate of 0.8 mill is accepted as fair for Lake freights—and for 1898 the average rate was 0.79 mill—and a retardation of 50% for the entire distance of 500 miles between Buffalo and New York is assumed, the freight charge should be 60 cents per ton.

If, on the other hand, a railroad rate of 3 mills per ton-mile for the 440 miles between Buffalo and New York is taken, the cost will be $1.32, making a difference of 72 cents per ton. At this rate, the transit of less than 22 000 000 tons would be required to directly pay the country for the expenditure. This amount is less than the average freight through the Soo for the three years ending with 1899. Obviously, to contend that, neglecting entirely all incidental benefits, there could be any loss to the country by constructing a 30-ft. canal through the State, it is necessary to show that either the estimate of cost is too low or an insufficient allowance for retardation has been made.

As the decisive element in this discussion hinges on the relation between the possible cost of a deep waterway from Chicago and Duluth to the Port of New York, and the probable saving in the cost of transporting the immense volume of freightage to be developed by the improved waterway, indulgence is asked for the presentation of another postulate: If it is thought that the previous estimate should be doubled to cover all contingencies, instead of having 50% added as before, the annual charge would become $22 190 000. Assuming that the expected 80 000 000 tons on the Lakes were carried the present average distance at a saving of 0.25 mill per ton-mile, it would leave $5 650 000 to be earned on the canal. If there was no larger saving per ton carried in the canal than the cost of transferring package freight at Buffalo, viz., 27.1 cents per ton, as mentioned by Major Symons, it would require only 21 000 000 tons to pass through the improved canal to repay the country the interest and maintenance on the entire outlay.

The above-estimated cost is supposed to be greatly in excess of any necessary expenditure, and, in view of the fact that the Government is borrowing money at 2%, the allowance of 3.5% for interest and maintenance will be thought sufficient. Deepening the Lake channels from 16 to 21 ft., and enlarging the locks, has resulted in reducing freight rates from 2 to 1 mill, and it is not probable that anyone will contend that a further deepening from 21 to 30 ft. would not force a greater reduction in rates than ¼ mill. The only ground for attacking the estimate appears to require a prediction that our producing, manufacturing and consuming capacity is about to be paralyzed.

Although a very large sum, compared with the cost of preceding public or corporate improvements, will be required for this work, it is suggested that there is no necessity for a partial improvement. The United States has not only abundant credit, but the necessary capital in hand to carry the enterprise to a prompt completion. And it is

Mr. North. confidently predicted that in no year will the expenditures on this improved waterway exceed our loans of the current year to foreign countries,—loans that aid them in industrial competition.

In a paper on the Suez Canal, lately read before the Institution of Civil Engineers, London, by Sir Charles Hartley, it is stated that questions addressed to many captains and pilots navigating that canal showed a consensus of opinion in favor of a canal that could pass vessels at a speed of 8 knots—9.22 miles—per hour. For this, 3 to 3½ ft. under the bottom of the vessel, with 1½ clear beam widths between vessels when passing, and 40 ft. between the vessel and the bank was desired, with an ultimate depth of 32 ft. 9 ins.

The present scheme for enlargement provides for a depth of 29 ft. 6 ins., a bottom width of 200 ft., or a cross-section of 8 075 sq. ft. Mr. Lionel B. Wells wrote, in discussion of that paper, that with a vessel said to have a speed of 11 knots in the open sea, he made 8 knots per hour in the canal. The cross-section of the vessel was 819 sq. ft., and the probable cross-section of the canal 5 384 sq. ft., or about 6½ times the cross-section of the vessel.

The Bureau of Statistics, in its "Miscellaneous Tables," gives the mean duration of passage of vessels navigating the Suez Canal by night and day as 17 hours 16 minutes, or an average of 5.8 miles per hour, including the necessary delays at "gares," as often as vessels meet.

It is noticeable that a depth of 29 ft. 6 ins. is being obtained, and a depth of 32 ft. 6 ins. is expected in a canal that for some time has not had half the traffic of the Soo, and probably will never pass one-fourth of the traffic of the Detroit River. The paper of Sir Charles Hartley, with the discussion, strengthens the general conviction that the speed of boats in contracted channels increases faster than the ratio of the cross-sections of the channels to that of the boats; and any desired speed can be maintained in a canal of sufficient size. The remarkable absence of accidents delaying traffic in the Suez Canal gives strength to the theory that accidents are less to be dreaded in canals than in comparatively short passages of restricted width in the course of a free navigation. And it should be remembered that while a small canal is impracticable for a large vessel, the small vessel moves with less expense than in a more contracted channel.

It seems that with a channel of sufficient cross-section to conveniently accommodate the tonnage which may be fairly expected, the saving in the cost of the freight carried will more than pay the assumed rates of interest and maintenance. And that, without regard to indirect and collateral benefits, the investment will afford a profit to the public after paying interest and maintenance charges.

With these considerations, it does not seem entirely proper to imagine a canal of inadequate capacity and predicate on that conception the necessity of high freight rates because of a speed of "only 5 miles per hour." Mr. North.

The very full and complete statistics kept by the engineer corps at the Soo, which cover the last thirteen years, show that concurrently with deepening and enlarging the Lake channels, and, it is confidently thought, in consequence of such deepening, the tons carried in 1887, 5 494 649, increased to 25 255 810 in 1899, while the cost for such carriage increased from $10 075 153 to $21 959 707. A very important relation of this traffic to the production and wealth of the country is shown by the fact that, while the value per ton was $13.83 in 1887, reaching its minimum, $10.59, in 1895, and averaging $11.14 for the thirteen years, the cost of transportation, compared with the value of the freight, has decreased from an average of 10.88% for the three years ending with 1889, to 6.34% for the three years ending with 1898, having averaged for the thirteen years 7.84% of the value of the goods transported an average distance of 827 miles.

It is unnecessary to explain the effect of this low freight rate on the production and wealth of this country, much of the produce having been sold on Lake Erie docks for less than the railroad charges between the points of production and sale, according to E. S. Wheeler, M. Am. Soc. C. E., for some time superintendent of the locks at the Soo. The cost of transportation by railroads would probably have prevented the production of fully half the freight carried, as they would have left only about 45% of the value to the producers. And the low freight rates on the Lakes have been an important if not governing factor in our ability in the nine months ending with September 30th, 1900, to sell manufactured goods valued at over $338 000 000 to foreigners. During the period under consideration the total value of the 169 333 701 tons passing through the Soo was $1 986 374 573, and $155 798 436 was received for its carriage on the Lakes. If this ton-mileage had paid railroad rates, it would have cost over $1 000 000 00 more. This sum applied to the total expenditures of the country for rivers and harbors—$320 000 000—gives a very satisfactory dividend. Comparing the railroad rates of 1899 with the water rates, there is a saving of $129 715 811, or a dividend of 40.5%, on the above-mentioned expenditure.

It is recognized that objections are made to taking the average of all railroad freights in comparison with water rates on lower-classed goods, but as a rough measure the method may be inadequate, in view of the facts that the tonnage through the Soo is about half of the traffic on the Great Lakes, and our average freight rates, which are less than half those of any other country, are declining rapidly. This is due more to the competition developed by our ample Lake channels than to any other cause. If the entire cost of transportation must be taken in some proportion from the resources of both producer and

Mr. North. consumer, it is probable that the direct gain to the people served by the enlargement of the locks and channels during the last thirteen years is greater than $2 000 000 000, rather than less than $1 000 000 000. This is in addition to indirect gains from the employment given in producing such part of the $1 986 374 570 as was made possible by low freights and the consumption consequent on such production.

History takes no cognizance of an occasion when a proposition to enlarge channels of distribution and cheapen transportation has been submitted to the public without decided opposition to the project from those having an interest in existing transportation facilities. Most of us remember the Lake Carriers opposition to General Poe's plan for a 20-ft. navigation, and Thomas C. Keefer, Past President of this Society, in a paper—"The Canals of Canada"—read before the Royal Society of Canada in 1893, has preserved a record of some of the influence brought to bear on a Commission appointed by the Dominion Government in 1870 to decide on the depth of the Canadian Canal system.

A ship owner, of Oswego, thought vessels 200 ft. long with a burden of 750 tons "ample for the internal commerce of the Lakes, the Lower Provinces and New England; longer locks would cause expense, a strong current and delay, not warrantable in order to provide for a few and rare cases where large vessels would desire to pass to and from the ocean."

Another, "whose life had been spent in the commerce of the Lakes" said:

"It had been clearly established that vessels of over 700 or 800 tons were not so profitable on the Lakes as vessels of a smaller size. Nature has placed barriers in front of most of our harbors, also wide flats across some of our greatest thoroughfares, that will, in spite of art, for ages to come, make it necessary to build lighter-draft vessels. Sail vessels of over 800 tons could not safely navigate the lakes even if harbors were deep enough."

Mr. Keefer does not make it entirely clear whether this testimony is preserved to palliate the insufficient size of the Canadian canals, or to show the exuberant imagination developed by the possession of some small wooden schooners, in the minds of otherwise reliable citizens. The conclusions and opinions reproduced bear a striking resemblance to some published thirty years later by the Committee on Canals of New York State.

Notices of large-sized steamships which have been built lately, for as certain an ocean trade as that on the Great Lakes, seem to be responsible for a theory that all over-sea commerce is carried in ocean leviathans, and that if we cannot have ocean leviathans we cannot trade. But the sea-borne exports from the United States are carried in vessels that average 818 tons net register; 32 108 vessels with an aggregate of 26 265 976 net registered tons cleared from our ports in the

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foreign trade during the fiscal year 1899. The average register of sailing vessels was 371 tons, and of steamships 1 064 tons. As a matter of comparison, the American sail vessels passing through the locks at the Soo during the calendar year 1899 averaged 944 net registered tons, and the American steamers 1 162 tons, or nearly 9¼% greater tonnage than those engaged in our foreign trade. And the vessels, sail and steam, carrying our exports to foreign countries averaged only three-quarters of the tonnage of our vessels carrying between Lake Superior and the lower lakes.

The steamships out of the Port of New York, in our export trade, averaged 2 324 tons; those to English and European ports north of Gibraltar, 3 055 tons. To the Mediterranean, the average was 2 104 tons; to South American ports, 1 517 tons, and to West Indian ports, 1 453 tons.

The greater average tonnage to ports north of Gibraltar is due in part to their larger consumption, and in part to our necessity of shipping *via* those countries whose persistent subsidies to steamer lines has enabled them to become distributors of the goods of less alert nations to those small but more profitable markets which are not reached by direct lines from this country.

Although there is no doubt that the large vehicle with full loads always carries freight at a lower cost than the smaller one, the small carrier is necessary to commercial development and occupies the same position to ports of smaller production that our cheaply constructed railroads of the '40's and '50's held in the development of this country. A large commerce is as impossible without development by the small carrier as the four-tracked railroad would be without its forerunner, the cheap road.

Much has been said about barge and other towing on the Lakes, the Atlantic and on rivers. Towing on the Lakes, though theoretically economical, has not proved sufficiently profitable in practice to receive much development. The peculiar fleet-towing on the Ohio and Mississippi, viz., the towboat pushing the fleet or holding back in bends, gives probably the cheapest transportation known, but that method would be impossible on the Lakes, of doubtful practicability on any canal, impracticable in a stream like the Hudson, where the tide ebbs and flows from New York to Troy, and would be dangerous at times in the Tappan Zee with the style of boats used on the Ohio. String and fleet-towing are both practicable on nearly all rivers, and there seem to be no theoretical objections to its economy; but, excepting fleet-towing on the Hudson, it has not been much developed in this country.

String-towing has for some time been practiced both on the Lakes and ocean, particularly in the coasting trade. At one time the large coal railroads moved substantially all of their coal to eastern ports by

Mr. North. towboats and barges. In the dark days between 1893 and 1897 it was thought the coasting schooner was doomed. It is asserted that for one year only one schooner was launched in eastern ship yards. That is now ancient history. For some time there has not been a vacant berth in an eastern yard. A list of this year's launchings shows eighteen 4-masted to 6-masted schooners, averaging over 1 700 tons gross register each. The coal companies will doubtless continue towing barges along the Atlantic coast, but it is doubtful if that method of transportation will again attain the relative importance of four years ago; it, however, does not seem likely to be discontinued, and will probably always present a means of cheap transportation.

Fear is felt by some that foreign governments would subsidize steamer lines to our Lake ports and not only capture the trade of the Lakes, but destroy the ship-building industry established there. Such fear does not seem well founded. No vessel under a foreign flag could do a way business between any ports in the United States, and, though a few foreign steamers would discharge and load cargoes at Lake ports, their entire participation in that traffic would probably not exceed the 2 to 4% of British tonnage now passing the Soo. But it can be confidently predicted that, with a practicable channel to the sea, there are few vessels which would not add to their cost the 8 to 10% necessary to put in condensers and enable them to compete for the very high ocean freight rates now exacted, which are substantially paid by our producers.

This theory, that either American carrying or American ship building would be injured by an ample waterway connecting the Lakes and ocean together, has great doubt thrown upon it by the attitude of the agents of foreign steamships sailing from our ports and that of their employees and other servants. These lines are generally subsidized by the governments whose flag they fly, governments that know what they are paying their money for, and their agents in this country must uphold the interests of such governments, as well as the interests of the stockholders and those of the closely affiliated railroads in this country, or make way for some one better fitted for the position. It is doubtful if, in the whole category, a single advocate for anything larger than a barge canal can be found. And the fear that a ship canal of ample cross-section would enable these foreign shipowners to increase or even maintain their present high rates for freight and passengers seems to have no more foundation than a fear that the same canal would allow the New York Central to maintain either its general freight rates or its discrimination against the profits of our wheat growers.

The importance, to our national prosperity, of our present low freight rates and their further development in this direction cannot be overestimated. Any history treating of national power, from the Mr. North. dim days when its seat lay on the Euphrates route between India and the then West, to the present, shows, probably without assertion, that possession of the cheapest and most efficient transportation has been necessary for the greatest development of production and wealth.

Forty years ago Great Britain possessed the cheapest internal transportation, and, while seeing the destruction of our merchant marine, was building up its own with subsidies of nearly £1 000 000 per annum. In the aggregate rewards of its industrial energy it was apparently unapproachable. But the principle of conserving vested rights has enabled the managers of her railways to maintain freight rates without sensible diminution during this period, and prevented competition from enlarged canals. Other nations, however, have enlarged their waterways and reduced freight rates. Then, England stood easily first among the nations and this country third. Now, the United States, having the lowest freight rates, stands first, and there is doubt whether England, whose manufacturers and consumers pay more per ton-mile for transporting their freight than any other people, stands second or third in rank.

The managers of our railroads, unable to establish legislative principles analogous to those of England, except possibly along our northern seaboard, have adopted the expedient known as "community in stock ownership" with the apparent, if not avowed, intention of preventing healthy, or other, competition in the future. Success in this plan will probably result in no further diminution of freight rates in this country, unless there is more effective competition from water routes. Few doubt that the opening of the combined Lake and canal route in the spring still influences, and to some extent controls, all freight rates east of the Mississippi, as they did to a greater extent when Mr. Fink gave his testimony. None can doubt that a larger waterway than the present would have more influence; nor can it be denied that the larger the waterway, the greater the influence exerted by it. The only tenable question is as to the economical size of the canal.

Approaching the discussion of these papers with a predilection in favor of large channels, that some might call a prejudice, a collation of the figures, presented from year to year by the members of the United States Engineer Corps in charge of the locks at the Soo, showing the important items of the traffic, has resulted in astonishment at the combined growth of tonnage and decrease in cost of transportation, both absolutely and in terms of value carried. They show a traffic that is unprecedented for volume per inhabitant served, and is also thought to be unprecedented in both the small value per unit of commodities carried and in the low cost of the service. This is from

Mr. North. a lake, the shores of which were visited by the explorers of sixty years ago.

When the first locks at the Soo were opened to traffic we were a poor nation, and capital for small enterprises was secured with difficulty, mostly from foreigners at money-lender's bargains. To-day we seem to be the world's favorite gathering ground for national loans.

A consideration of the curves of increase and decrease, shown by these returns, and their extensions, have appeared to justify the foregoing assumed increases in tonnage and decreases in cost of service. They also are thought to warrant the prediction that no channel from the heads of the Great Lakes to the Port of New York in the service of distribution between the area which seeks outlet on that channel and the Atlantic coast of our country, will be so large as not to be inconveniently crowded by the passing traffic. The direct returns from the lower freight rates, on an ample and commodious channel, will undoubtedly exceed the annual expense to the nation for interest and maintenance.

As the statistics referred to may not be easily accessible to all members of the Society, they are given in Tables Nos. 2 and 3, with the addition of the railroad rate per ton-mile, as given in Poor's Manual, and some calculated deductions.

TABLE No. 2.—NET REGISTERED TONNAGE PASSING THE LOCKS AT SAULT STE. MARIE (THE SOO).

Year.	Tonnage.	Year.	Tonnage.	Year.	Tonnage.	Year.	Tonnage.	Year.	Tonnage.
1855	106 296	1864	571 438	1873	1 204 446	1882	2 468 088	1891	8 400 685
1856	101 458	1865	409 062	1874	1 070 867	1883	2 042 259	1892	10 647 203
1857	180 820	1866	458 530	1875	1 259 534	1884	2 997 837	1893	8 949 754
1858	219 819	1867	556 899	1876	1 541 676	1885	3 035 937	1894	13 110 366
1859	352 642	1868	432 563	1877	1 439 216	1886	4 219 397	1895	16 806 781
1860	403 657	1869	524 885	1878	1 667 136	1887	4 897 598	1896	17 249 418
1861	276 639	1870	690 826	1879	1 677 071	1888	5 130 659	1897	17 619 933
1862	359 612	1871	752 101	1880	1 734 890	1889	7 221 935	1898	18 622 754
1863	507 434	1872	914 735	1881	2 092 757	1890	8 454 435	1899	21 958 347

Lock.	Dimensions.	Date of opening.
First lock; double lift.........	350 × 70 × 11½ ft.	June 18th, 1855.
Weitzel lock....................	515 × 80 × 17 ft.	Sept. 1st, 1881.
Canadian lock............	900 × 60 × 20 ft.	Sept. 9th, 1895.
Poe lock.......................	800 × 100 × 21 ft.	Aug. 3d, 1896.

NOTE.—Deepening the lake channels from 16 ft. to 21 ft. was commenced in the spring of 1893 and completed in 1898.

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TABLE No. 3.—TRAFFIC THROUGH THE LOCKS AT ST. MARY'S FALLS, OTHERWISE CALLED "THE SOO."

Year.	Tons carried.	Ton-miles.	Average distance.	Lake cost of carriage.	Cost per ton-mile.	Average railroad freight rates per ton-mile.	Railroad cost for equal ton-miles.	Total value of freight carried.	Value per ton.	Percentage of value paid for transportation.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
					Mills.	Mills.				
1887........	5 494 649	4 458 544 804	811	$10 075 153	2.3	10.34	$46 101 353	$79 031 757	$13.83	12.75
1888........	6 411 423	5 173 132 972	806	7 883 077	1.5	9.77	50 541 509	82 156 019	12.81	9.59
1889........	7 516 022	5 940 646 352	790	8 634 247	1.5	9.70	57 624 270	83 732 527	11.14	10.31
1890........	9 041 213	7 207 299 415	797	9 472 215	1.3	9.27	66 811 666	102 214 948	11.30	9.26
1891........	8 888 759	7 292 462 269	820	9 849 023	1.35	9.29	67 746 974	128 178 208	14.42	7.68
1892........	11 214 333	9 222 773 938	822	12 072 851	1.31	9.41	86 786 303	135 117 267	12.49	8.93
1893........	10 796 572	8 980 310 240	832	9 957 483	1.10	8.93	80 194 170	145 436 957	13.47	6.84
1894........	13 195 860	10 927 871 324	821	10 798 310	0.99	8.64	94 116 808	143 114 502	10.80	7.54
1895........	15 062 580	12 502 548 892	830	14 238 758	1.14	8.39	104 896 385	159 575 129	10.59	8.92
1896........	16 239 061	13 582 641 886	836	13 511 616	0.99	8.21	111 513 490	195 146 842	12.02	6.87
1897........	18 982 755	15 969 393 576	841	13 220 100	0.83	7.97	127 276 067	218 235 927	11.49	6.06
1898........	21 234 664	17 891 597 030	843	14 125 896	0.79	7.58	135 618 305	233 069 740	10.98	6.10
1899........	25 255 810	20 891 944 628	827	21 959 707	1.05	7.26	151 675 518	281 364 750	11.14	7.80
Totals and averages.	169 333 701	140 041 167 326	827	$155 798 436	1.11	8.43	$1 181 202 818	$1 986 374 573	$11.14	7.84

Mr. Monro.

THOMAS MONRO, M. Inst. C. E. (by letter).—Mr. Wisner makes out a fair case for a 21-ft. channel, but the writer must take exception to the way in which he has bracketed the "decline of traffic on the Erie Canal since 1880," with the alleged "failure of the 14-ft. Canadian canals to divert commerce from the lake and railroad lines." It is true that the traffic of the Erie Canal, at its present dimensions, is constantly declining—and for obvious reasons—but the 14-ft. channel between Lake Ontario and the sea has not yet been tried, and, therefore, cannot correctly be said to have failed. As is well known, the Canadian canals were only fully opened to the new dimensions this spring, and there are as yet but few vessels of full "Canadian canal size" in existence. The fleet that can navigate the St. Lawrence route to the greatest advantage has yet to be built, but the writer believes that a number of suitable craft are now in hand on the Upper Lakes. As a matter of fact, only one vessel drawing 13½ ft. passed through to Montreal, so far, this season. The writer is inclined to believe, however, that the $65 000 000 spent by Canada on a line of navigation which will enable vessels drawing 14 ft., and carrying from 2 000 to 2 200 tons, to pass directly from Duluth, Fort William or Chicago to Montreal without breaking bulk, has not been entirely thrown away—but, on the contrary, this magnificent route, when fully developed, as it will be ere long, must prove a valuable means of transporting grain, ore, steel, etc., for export to Europe *via* Montreal.

If the arguments set forth in Major Symons report of 1897 are correct (and the writer believes this to be the ablest and most practical paper which has so far been written on the subject), and his conclusion sound, that the best thing New York can do is to construct a 10-ft. barge canal across the State 350 miles from Buffalo to Albany, then there appears to be a chance for Canada to do some business, on a 14-ft. basis, with boats of 2 000 tons, and only about 70 miles of canals between the Great Lakes and the seaboard. Of course, it is a fact that the domestic commerce of the United States, between the centers of population in the East and the producing regions of the West, constitutes the vast bulk of the present traffic; and the Canadian route does not lead directly either to the New England States or New York; but the development of Canada's own vast areas of production in the Northwest must soon give plenty of work to do. There will be enough to crowd all the avenues of transportation both by rail and water. The railways are making such rapid strides in cheapening freights that the water routes will have to look to their laurels. Brindley said that rivers were made to feed canals; but one would not now be surprised to hear of railway men proposing to fill them both up so as to form roadbeds for their ever-multiplying tracks. If the water routes fail entirely, as has been so confidently predicted, the Canadian route cannot prove the exception hoped for. At all events, Canada is past

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the theorizing stage. Its main canal system is now completed, such as it is, and, if it fail, all that can then be said for Canadians is that they deserve more credit for pluck than for foresight. However, the end is not yet, and the writer, for one, fully believes that Canada will, in due time, reap the full benefits of her large expenditure on her national route.

Mr. Hinds.

Frank A. Hinds, M. Am. Soc. C. E. (by letter).—Mr. Wisner's paper is valuable in that it shows the necessary dimensions a canal must have in order to do a successful business between the Great Lakes and New York, and Mr. Mayer's paper throws much light on the question of who should build it.

That the enterprise belongs to the United States and not to the State of New York alone, becomes more evident the more it is considered, although New York State will always be much interested in it, on account of its necessary location through her territory.

Nature made a great valley through the middle of New York State, cutting the Appalachian system of mountains below the level of Lake Erie and making it possible to construct a self-supplying waterway from this lake directly to tide water at Troy on the Hudson. In the report of the Deep Waterways Commission of 1897, this route, although mentioned, was not reported with favor, but, instead, a route was mentioned from Lake Erie to Lockport and to Lake Ontario at Olcott Harbor, and thence by way of Lake Ontario to Oswego and up again through the Mohawk Valley and finally down to Troy. The reasons given in favor of the Lake Ontario route were: Less standard canal to build; the development of new business on Lake Ontario, and a supposed saving in total length.

It would seem now, however, in view of the comparative speed which a vessel may be able to make in the canal, as is shown in the two papers under discussion, and also in view of the expense and difficulty of providing an adequate and reliable water supply for the summit of the Mohawk Valley Canal, that the subject of a self-supplying, continuously-descending-grade canal from Lake Erie to the Hudson should have further consideration.

The level of Lake Erie is 573 ft. above tide; that of Lake Ontario 247 ft. The long Rome Level of the present Erie Canal is 430 ft. above tide, or 183 ft. higher than Lake Ontario. Of all the business to be done on a waterway, probably more than seven-eighths would come from Lake Erie or points farther west.

Now, if, as recommended by the Deep Waterways Commission in 1897, the route is from Lake Erie through Lockport and Olcott to Lake Ontario, and thence by Oswego and Oneida Lake to Rome, all the through tonnage must be lowered to the level of Lake Ontario and then raised again to the Rome Level, making, as compared with a continuous-down-grade canal, twice the difference in level of 183 ft. from Lake Ontario to Rome, or 366 ft. of unnecessary lockage.

Mr. Hinds. A new canal would, of course, be made with fewer locks and greater lifts than was the old practice, but the delays consequent upon 366 ft. of lockage would offset any advantage of greater speed to be made by vessels while in the open lake between Olcott and Oswego. The time required for this 120 miles of lake navigation at 12 miles per hour would be 10 hours, while in the standard canal, at 8 miles per hour, it would take 15 hours, or 5 hours more than on the open lake; but this would be a short time in which to accomplish the 366 ft. of unnecessary lockage. A comparison of the total distance over each of the two routes, although it cannot be made with certainty until each is carefully surveyed, would probably not disclose a great difference between them; but the probabilities are, judging from a study of the topographical maps of the United States Geological Survey, etc., that the shorter line will be found to be by way of the continuous canal.

With the continuous down-grade, the water from Lake Erie would practically supply the canal through to the Hudson, and avoid the very difficult problem of providing an entire water supply at the Rome Summit.

It is to be remembered that, where a canal passes over a summit, the water must be supplied at the top, and each boat in passing over requires a supply of water equal to the horizontal size of the lock multiplied by the total height of all the locks ascended or descended.

A ship canal passing over the Rome Summit Level, from Lake Ontario to the Hudson, requires a total lift of $183 + 430 = 613$ ft., and all the water for operating the locks in either direction must be supplied at the summit.

It was proposed, in the Deep Waterways report, to make a moderate development of the canal through western New York, with a high level from Newark to Syracuse, as a means of water supply for the Mohawk Valley Summit.

Now, if it is practicable to make a feeder along this line, then it cannot be very impracticable to make the feeder into a canal, and the cost of the first construction, and the maintenance of this feeder afterward, can be applied in the first cost of the continuous canal, which will be self-feeding. Lake Ontario may be fully accommodated and its interests as thoroughly developed by a side cut, probably through Oswego and the Oswego River, as it would if all the business from the Upper Lakes was compelled to pass down to its level and then be raised again over the summit.

With the necessary water supply reduced to a minimum, and it takes much less water for the through business if the unnecessary lockage into Lake Ontario is avoided, and with the supply of water coming from a source as constant and secure, and as well situated, as that of Lake Erie, it is plain that this route deserves more attention and consideration than it seems to have received.

Mr. Hinds.

With the work in the hands of the United States Government, it can certainly afford, if it builds a canal, to build the one that is best and most desirable for the whole country, and cheapest and simplest to operate.

Mr. Sweet.

Elnathan Sweet, M. Am. Soc. C. E. (by letter).—These papers, relating to the same propositions, and reaching similar conclusions, deepen the conviction the writer has held, ever since bringing this subject to the attention of the Society, in a paper read at the Buffalo Convention in 1884,* that no waterway built to connect these waters can hope to secure great commercial importance unless it can accommodate the largest vessels navigating the Great Lakes.

In a communication to the *Times*, opposing the endorsement of the proposition then before the people of New York to authorize the expenditure of $9 000 000 for slightly enlarging the State canals, the writer urged that "the expenditure of great sums of money for so-called improvements of the present canal were to be discouraged as wasteful, and because they tended to postpone the wise and statesmanlike undertaking of a deep-water outlet for Lake commerce."

There are three fundamental and controlling elements of advantage in the deep waterway:

First.—The elementary physical law, that the resistance to motion in vessels of like model varies directly as their immersed surfaces, while their tonnage varies as the cubic contents of their immersed section, ensures enormous economy in large boats.

Second.—The obvious and controlling advantage of passing from terminal to terminal without transfer of cargo.

Third.—A large fleet adapted to the navigation of the deep waterway already exists, while, to put the smaller canal into operation, a new marine equipment must be created, for which there could be little use elsewhere

Mr. Wisner makes a very strong argument, showing the disproportion of benefit to cost in the deepening of Lake channels and harbors beyond the depth of 21 ft., now in process of attainment by the Government engineers. This seems to the writer to afford definite authority for fixing the depth of the canal, and, in the light of the extended experiments made since 1890 in France and Germany on the resistance to traction in narrow channels, the writer thinks that the making of the wet cross-section more than five times as great as the midship section of the largest vessel it is intended to accommodate, will insure about two-thirds of the speed secured in open water with the same expenditure of energy; but for economy of movement with 19 ft. draft he thinks that the proposed form of section should be modified by increasing the depth 2 ft. and narrowing the width sufficiently to secure the proposed sectional area of channels. He cannot share the

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* *Transactions*, Am. Soc. C. E., Vol. xix, p. 37.

Mr. Sweet. sanguine expectation expressed by Mr. Mayer as to the volume of tonnage likely to soon seek transportation on such a canal. Its chief function will be the transportation of freight destined for Atlantic ports and for export. The ore and coal freights which form so large a fraction of lake tonnage cannot, under present conditions, contribute business to this canal.

It must be remembered that the railroads are the natural and necessary distributors of even the coarsest and heaviest freight, as their side tracks reach the yards of all large manufacturers and consumers throughout the country. A large part of the tonnage received by Lake at Buffalo and other Lake Erie ports is destined for distribution in the interior of the Eastern-Middle and New England States, and this freight will all probably continue to be handled from Lake ports by the railroads, for the reason that the branch roads making this distribution are controlled by railroads reaching these Lake Erie ports, and their control of local rail rates will enable them to route this business through from these ports instead of from points farther east on the canal.

There is a question of public policy to be considered as to the effect of withdrawing so large a part of the business of the railroads, in which so large a part of the capital of the country is invested, upon their earning capacity and the rates it would be necessary for them to impose on their remaining traffic.

Account should also be taken of the question whether all freights may not ultimately be handled more cheaply by rail, in favor of which there are both practical results and theoretical considerations.

The great and uninterrupted decrease in unit-cost of railroad freight transportation during the entire period since its introduction may be cited as the practical result, and the fact that the resistance to the movement of rail freight varies directly as the velocity and on account of the labor item is (within limits of safety to track and equipment) cheaper at high than at low speeds, while the resistance of vessels increases at a rate greater than the square of the rate of speed, and is absolutely greater than the rail resistance except at a moderate rate, may be urged as the principal theoretical consideration.

The fact that our resources are growing so rapidly, that the Lake Region and the line of this canal furnish the most suitable field for a great export business in heavy manufactures, and that the export freight business is necessarily carried on by water, make it probable that both the railroads and the canals will be needed in a future not remote, and both be profitable.

Mr. Hunter. W. Henry Hunter,* M. Inst. C. E. (by letter).—In responding to the invitation to take part in the discussion of a subject of such world-wide importance, the writer can but express his regret that lack of

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*Chief Engineer to the Manchester Ship Canal; President of the Manchester Association of Students of the Institution of Civil Engineers.

Mr. Hunter.

time and pressure of official engagements have rendered it impossible for him to find opportunity for the close and detailed study of the question which is rendered so necessary by the great issues involved in it, or to grasp anything more than the outlines of the different schemes which have been propounded; though in this particular the papers by Messrs. Mayer and Wisner have been of the greatest possible assistance.

It appears very clear to many outside the boundaries of the United States, that the time has arrived in which it is essential, even in the interests of their own country, that the economists and engineers of the United States should take more practical cognizance of the fact that their great Republic has an even more important part to play as an integral portion of the human family, than as a more or less self-contained community (or concourse of communities) dwelling alone, devoting itself to the development of its own resources, and the advancement of its own interests, whether material or moral.

The date of the accomplishment of the poet's dream of "The parliament of man, the federation of the world," is as far off as ever; yet, of nations as of individuals, it is true, and is becoming more and more apparent, that "No one . . . liveth to himself, and no one dieth to himself," for the interdependence of humanity is growing more and more pronounced as population increases, and as the reserves, in the way of uncultivated prairies and unwatered steppes, are being brought into use for the benefit of man.

Interdependence involves intercommunication: The one is a question for the economist, the other a matter for the engineer; the present danger is that in each case too narrow a view may be taken, either of the responsibilities of the position, or of its possibilities.

The problem of the future, the not-far-distant future, will resolve itself into the broad question of the supply of food to the rapidly increasing masses of mankind. Civilization is becoming effective at last, and the result is that population is growing at an unprecedented rate, so much so that the academical question—the question of the theorists—of former generations, as to the sufficiency of the earth for the support of her children, will soon loom largely on the horizon of practical politics, and men will have to rouse themselves to deal with it.

If this were admitted and its significance realized, proposals for constructing barge canals, or even ship canals of insignificant depth, between the Atlantic seaboard and the Lakes which form the natural center of one of the greatest food-producing districts on the earth, would drop into the limbo of "lost causes"; the insufficiency of either one or the other would become so manifest.

The first and greatest of the means of intercommunication on our planet is of Nature's providing, is the ocean; whether in the East or in

Mr. Hunter. the West, the sea is the trunk highway for mankind; and the primary object to be sought in the projection of a waterway originating on the seaboard, and consisting, as is generally the case, (*a*) of the improvement of a river, (*b*) of the formation of a canal, should be the carrying of the sea as far into the interior as is reasonably possible; for the farther the sea is carried into the interior, the greater will be the benefit to the district affected, and the more marked will be the ultimate success of the waterway.

The Manchester Ship Canal furnishes an example of a waterway of this class. The terminal docks are 50 miles inland from the coast line, a distance which is covered by 15 miles of estuarial and river improvement, and 35 miles of canal construction, construction which was carried out in the midst of a dense population, in the teeth of bitter and prolonged opposition, and in despite of a crowd of ancient rights and vested interests, which are always short-sighted, inert, and desperately opposed to progress, but which, in a country like Great Britain, must be reckoned with, must in some cases be conciliated, in others coerced. Either process costs money, hence the Manchester Canal cost more than it should have cost, to which cause, added to that presented by the obstructions thrown in the way of its working by the same vested interests, is due the fact that up to the present time it has returned no reward in the shape of dividend to its original shareholders.

This fact had led pessimistic persons to the conclusion that the canal has failed in the accomplishment of the purpose for which it was promoted and constructed There never was a greater fallacy, a greater error. A prominent public man in Manchester,* the head of one of the largest manufacturing firms in England, has declared again and again, and has met with no one bold enough to deny his proposition, that the citizens of Manchester are receiving more than 20% per annum for the $25 000 000 which the city invested in the canal, while directly and indirectly the canal has influenced for good a district in which the population is more dense than in any other on the face of the globe, and has sensibly advanced the welfare of some 10 000 000 human beings. At the same time trade is growing, developments are accruing, terminal facilities are being increased and extended, and the cost of handling traffic diminished to such a degree that there is every prospect of a return being made ultimately, even to the patriotic shareholders who put their money into the undertaking.

The depth to which the Manchester Ship Canal was constructed was 26 ft., but the sills of all the locks were put down to 28 ft. Steamers of a dead-weight capacity of 10 000 tons are now traversing the canal regularly, and others, still larger, are projected. Thus it is clear that the deepening of the waterway to 28 ft. will have to be taken in hand at no distant date, for the course of trade is now such that large steamers can run and prove themselves profitable to their owners, where small or even moderate-sized vessels cannot live. Mr. Hunter.

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* Mr. Reuben Spencer, the head of the firm of John Rylands & Co.

Applying this experience to the case under discussion, which is really not one of carrying the sea inland, so much as it is one of joining two seas, or, in other words, of severing an isthmus, it would appear that a dead-weight capacity of 8 600 tons for the ocean-going steamers proposed to be sent on, *via* the new waterway, to Chicago, would be insufficient. Such steamers would hardly compete now with the large and improved boats which are continually being launched, and in twenty years' time they would be altogether out of the running. If the canal were formed with a depth of 24 ft. in the first instance, and all lock sills, syphons, and other works which would limit the possibility of future deepening, were put down to 30 ft., it is probable that the waterway would meet the world's needs for the next half century, which is all that can be required.

The regulation speed of vessels on the Manchester Canal is, as stated by Mr. Wisner, 6 miles per hour, but licenses are issued to steamers permitting them to run at the rate of 8 miles, as experience has proved that at this speed no sensible amount of injury is caused to the banks by wash; the licenses are, therefore, granted as a matter of course, there having been only one instance in which the writer has had to refuse his consent to the issue, and that was in the case of a large paddle steamer (an undesirable craft on a canal), which was already really running at the rate of over 8 and wanted to run 10 miles per hour. There need, therefore, be no apprehension as to the safety of the estimate of 8 miles per hour as the average speed of large steamers on the proposed Lakes Canal.

The writer would like to add one observation in respect of the argument that if the Lakes Canal were really required "the play of economic forces" would be sufficient to bring about its construction. The economic theories—or principles, if the word is preferred—of one age become the fallacies of another, as life becomes more complex, and the interdependence, to which reference has already been made, grows more complete. From this proposition, if sound, it follows that strict adherence to theories as to demand and supply, as if these theories were natural laws which could not be broken with impunity, would inevitably arrest the advance of civilization and the progress of the human race.

The ordinary investor, as such, is neither a philanthropist nor a patriot—he does not think—nor indeed is it possible for him to think, except in a secondary way, of the good of mankind, of which he is a part, or of the welfare of the State, of which he is a subject. On the contrary, his operations are governed wholly by the prospect of return for his investment in the form of interest upon his capital. It is clear, Mr. Hunter. therefore, (1) that public works of the first magnitude—arterial lines of communication and the like—which are, in the first place, for the public benefit, can present little of attractiveness to the investor, (2) that such works will never be made out of private money (any more than ironclad line-of-battle ships can be built, or coast defenses constructed, out of private money), and (3) that, as it cannot be denied that they are a necessity for the public welfare, the public, that is to say, the State, must of necessity provide the funds required for their construction and equipment; and this despite the instinctive tendency of the Anglo-Saxon race to depend in these matters upon private enterprise rather than upon governmental energy.

In the opinion of the writer, the advantages, direct and indirect, which would accrue to the citizens of the United States from the construction of the canal between New York and the Great Lakes would be so profound and far reaching, and the increase of the prosperity of the community would be so marked that the Central Government would be justified in forming the canal and in throwing it open to the trade of the world at the smallest possible toll charge; he claims that the case of the Manchester Ship Canal, and of the benefit which its working has been proved to have conferred upon the greatest manufacturing district on earth, furnishes a firm basis for this opinion, and he desires to thank the American Society of Civil Engineers and the authors of the papers under discussion for affording him an opportunity of expressing it.

Mr. Hoech. THEODOR G. HOECH, M. Am. Soc. C. E. (by letter).—The report of the New York Canal Commission on a barge canal of 12 ft. depth, and other studies of improved waterways between the Great Lakes and the metropolis on the Hudson River, after the able report of Major Symons recommending a barge canal 12 ft. deep, cannot fail to prove, even to a distant observer, the growing interest of the engineering profession in an improved waterway, and at the same time a sentiment for greater dimensions for this modern canal.

Not being able to check the figures presented, the writer may be allowed to point out some commercial features of North America's Atlantic slope affecting inland navigation.

The commercial power of the City of New York seems to be so great that the exporting merchants do not think of running ocean steamers up the Hudson River with the flood current to meet the canal boats as far inland as possible, as is the case in several European rivers. One could figure out, however, that the cheapest way of exporting western goods would be to carry them by barges or lake steamers, say, to the Hudson, and to transfer them there into large transatlantic steamers. It is to be considered a silent but great compliment to the harbor of New York that nobody advocates this waterway system, promising the cheapest rates from West to transatlantic ports.

New York's attractive and accumulating power seems also to have prevented the commerce from passing in greater degree through the Canadian canals of 14 ft. depth. Mr. Hoech.

That dominant position of New York will; of course, be of deciding effect on the final solution of the waterway question, and the fact should not be overlooked that with a ship canal ocean steamers would pass the metropolis of the Atlantic Coast, and allow European freighters to run into the Great Lakes as far as Duluth, and take the grain of the West to Europe, without transfer and harbor expenses. It does not seem likely that New York will part with the many petty charges and profits derived from distributing and transferring goods.

One may safely presume that the City and the State of New York will construct a waterway satisfactory to their interests, which commercially will be of the same kind as the old Erie Canal—and will strengthen still more the great center on the Atlantic Coast. It is important to the city that all transfers between the Lake harbors and New York should be done away with, while retaining the transfer business, and this condition can be satisfied by a large barge canal.

In Germany, the number of barges—Seeleichter—is growing rapidly, and these barges run safely from the Rhine and the Dortmund-Ems Canal through the German Sea, and the Kaiser Wilhelm Ship Canal to the Baltic Sea—the Great Lake of Northern Europe. Besides these towed barges, twenty-five small steamers are running regularly from Koeln on the Rhine to London, Hamburg, Dantzig, etc.

The growing sentiment for greater dimensions for new canals may, in the writer's opinion, lead to a barge canal of 14 ft. depth, after some further discussion. This would give a fair field for competition and comparison between small freight steamers and large barges, and the results would be watched with great interest everywhere.

The advantages of a 14-ft. barge canal, which would take care of the business concerned for some time, may be stated as follows:

First, it would mean a great step in advance without changing the commercial position fundamentally, and the canal itself could be constructed in two parts: With a deeper canal from the Mohawk Valley to Lake Ontario in operation, steamers and barges could make use of the Welland Canal, allowing the time for building the Niagara Canal and the fleet of standard vessels.

Secondly, the fleets of steamers and barges would be enhanced in value on account of the two outlets to the ocean, and even a third one from Chicago to New Orleans, which can be hoped for.

Without strong reasons for a change, the dimensions of neighboring waterways, even when a little less profitable, should be accepted. The Canadian canals may keep their present dimensions for many years to come, and the ship canal from Chicago to New Orleans may not come at all, for two reasons. After a ship canal is built from the

Mr. Hoech. Great Lakes to the Atlantic Coast, no second ship canal would be needed to the Gulf, for no ocean steamer would choose such a long inland waterway in competition with cheap river steamers and still cheaper barges. But a deep barge canal from Lake Michigan to the Mississippi, and another one from Lake Erie to the Ohio River, would form, with the Canadian and the New York canals, a great system of uniform waterways opening half a continent to steamers and barges of standard dimensions.

Mr. Noble. ALFRED NOBLE, M. Am. Soc. C. E. (by letter).—The time required for the passage of a ship through the proposed Deep Waterway is perhaps as likely to provoke discussion as any point in Mr. Wisner's paper. The writer, having taken part in the investigation from which Mr. Wisner's conclusion resulted, will present an outline of it.

The movement of a ship through the artificial channels of the Deep Waterway would be obstructed by two different sets of causes: 1st. Reduction of speed due to the restricted dimensions and curvature of the waterway and the meeting of ships therein; and 2d, delays for passage of locks.

Any restriction in a waterway, whether of depth or width, will cause a reduction in the speed of a ship passing through it. Lake St. Clair furnishes an example of a waterway where the restricted dimension is depth, the width being several miles. The logs of two ships, each loaded to within 2 ft. of the bottom of this lake, showed a reduction of speed of 16 to 18%, as compared with the speed of the same ships in the deep water of Lake Huron. While data on this point are not as numerous as might be desired, it was believed to be on the safe side to assume a reduction of 20%, which was adopted in the investigation referred to. New data, collected since the close of the investigation, confirm those used.

If the width of the waterway is also restricted, new retarding conditions result. When the ship moves forward its length, a volume of water equal to its displacement passes between the ship and the bottom and sides of the waterway to maintain the water level, creating a back current. If the speed of the ship through the water remains the same as in wide, shoal water, its speed past a fixed land point will be reduced by the speed of the back current. In the investigation this reduction was made, although the amount appeared to be somewhat excessive, because, in the first place, the proper reduction was already in part provided for by the adopted reduction of 20% for the effect of shoal water, and, in the second place, because the amount of water transferred from the bow of the ship to the stern was calculated as the product of its midship section by its length, without allowing for the reduced sections near the bow and stern. The calculated back flow was therefore too great, and the reduction of the speed of the ship as taken was too great.

Mr. Noble.

To create the back flow and maintain it past the ship requires a head of water which opposes the movement of the ship. This, however, the investigation showed to be unimportant in the wide channel adopted for the waterway and with the speeds to be permitted in it.

These reductions of speed were applied in the case of a ship having a speed of 12½ miles per hour in the deep, open lake, resulting in speeds, with the same expenditure of power, varying from 8.2 miles per hour, in the ordinary section 215 ft. wide at the bottom, to 9.5 miles per hour in a channel 1 000 ft. wide at the bottom.

An investigation of this kind must be supported by experience, to be trustworthy, and therefore the actual movement of ships in other canals was examined with great care.

Manchester Canal.—The bottom width is 120 ft., the depth 26 ft., and the cross-section is about 4 400 sq. ft. in earth sections. In a paper presented to the VIIth International Congress on Navigation, in 1898, the Chief Engineer, Mr. W. H. Hunter, gave the dimensions of a number of vessels which traversed the canal at speeds varying from 7.3 to 13.6 miles per hour. The slower rate was for a ship 255.3 ft. long, 33.7 ft. beam, drawing 17.6 ft. The largest ships traversing the canal are about 450 ft. long and 50 ft. beam. The writer accompanied one of the ships for several miles and carefully noted its speed. It was loaded to within a few inches of the canal bottom, and therefore steered badly, requiring the aid of tugs, but the speed reached 6 miles per hour. In the consideration of the permissible speed in a waterway, either from a theoretical or practical standpoint, the ratio of the area of the ship's immersed cross-section to that of the water, is a controlling feature. In the case of the ship just mentioned the area of the cross-section of the waterway was 3.7 times the immersed cross-section of the ship. This ratio will be designated r.

Suez Canal.—When opened, and for many years afterward, the bottom width of the Suez Canal was 72 ft., and ships were permitted to move at the rate of 6.2 miles per hour. The value of r for the larger ships was probably a little greater than 3. The bottom width of the standard section of the Deep Waterway is almost exactly three times as much, and the cross-section of the largest ships traversing it will probably not be as great. If the comparison be made by means of the ratio r, its value for the largest ships expected in the Deep Waterway will be 5.5, instead of 3, as at Suez. Whether the comparison of these ratios, or of bottom widths, be made, a speed of 8.2 miles per hour in the Deep Waterway will appear to be much safer than one of 6.2 miles in the Suez Canal.

As to the practicable rate of speed and degree of security attainable in an artificial waterway, no better example can be cited than the St. Clair Flats Canal, where serious accidents seldom or never occur. This is believed to be the most crowded waterway in the world. The

Mr. Noble. maximum speed permitted by regulations is 8 miles per hour, but the largest freight steamers frequently pass at a higher rate; the largest passenger ships attain a rate of 11 to 13 miles per hour and a speed of 15.4 miles per hour is of record.

With these examples in view, the speed of 8.2 miles per hour in a straight waterway of 215 ft. bottom width appears moderate. The width is to be increased on all curves of less than 12 000 ft. radius, the widening being 1 ft. for each reduction of 200 ft. in the radius. A reduction of permissible speed, equal in miles per hour to

1.5 × degree of curve,

is made in the standard canal section, the reduction being reduced where the bottom width is greater. While this allowance is purely arbitrary, it is believed to be sufficient.

In the Suez, and other very narrow waterways, one of two meeting ships ties up. This is not found necessary in the artificial channels in the Great Lakes system, but the speed of both ships is reduced. In the 300-ft. channels of the St. Mary's River, where the channel banks are submerged, the regulations provide that the speed of both ships shall be reduced to 6 miles from a permitted speed of 9, and, excepting in special localities where the current is very strong, this has been found sufficient. In the somewhat narrower channel of the Deep Waterway the assumed reduction of speed is to about 4 miles per hour. The number of meetings is deduced from an assumed traffic of 25 000 000 registered tons annually carried in ships averaging 2 500 tons net register, or 10 000 ships per year. This discussion thus far relates to channels in earth. Objection may be made that in channels in rock with rough sides such speeds would be dangerous. The reply to this would be that no such channels are contemplated. In rock the bottom width is to be increased and the sides made vertical, by channeling machines where the rock is sound, and by retaining walls where these are necessary.

The delays at locks will not be discussed here in like detail; briefly, the allowance for these delays is based on ample experience at the St. Mary's Falls Canal in the movement of ships and the other operations of locking. In addition to this a considerable period has been allowed arbitrarily for delays at lake points where, after storms, vessels may occasionally arrive more rapidly than they can be passed through the next lock, and for smaller delays at each intermediate lock.

In designing this waterway the view has prevailed that it would not be worth making unless it were adapted to more speedy navigation than the principal foreign canals. A much wider prism and better lock facilities are therefore provided, and it is confidently believed that the estimates of time required for passage through it will stand investigation.

Lewis M. Haupt, M. Am. Soc. C. E. (by letter).—These papers open up a broad field for discussion, not only in engineering and economics, but in administration and statecraft. Mr. Haupt.

Mr. Randolph's succinct discussion contains much in little, and is certainly a sagacious compromise, as it makes provision for the progressive expansion of the capacity of the waterway.

Experience has invariably demonstrated the inadequacy of rigid dimensions to keep pace with the growing demands of commerce and the necessity of a flexibility which will adapt itself to the rapid growth of tonnage.

As early as 1847 (before the Sault Canal was seriously thought of) the late J. J. Abert, Hon. M. Am. Soc. C. E., Colonel, U. S. Topographical Engineers, discussed the "Probable Increase" of the Lake trade, in an official report to Mr. Marcy, Secretary of War, in which he said:*

"It is difficult to approach this part of the inquiry without fear of appearing to exaggerate. Those who knew these Lakes thirty years ago, and who know them now, will admit that existing facts have baffled human expectations, and that the wildest speculations of the imagination have been more than realized in the vast increase of their commerce. Then, if we examine into the elements of this increase, we can perceive no reason to doubt a less energetic action of these elements, for many years to come, than has been realized in the past."

That this forecast has been fully justified by subsequent events is confirmed by the statements of General O. M. Poe, whose investigations of the tonnage through the Lakes well qualified him to state the facts. He said:

"For thirty-five years I have watched the increase of the Great Lakes commerce, but neither I nor anyone else has been able to expand in ideas at the same rate. The wildest expectations of one year seem absurdly tame by the side of the actual facts of the next."

In view of this experience, it is somewhat surprising to read that so keen a statesman as Henry Clay opposed Hon. John Norvell's motion to construct this canal, in 1840, by the statement that it was "a work beyond the remotest settlement in the United States, if not in the moon."

Henry Clay evidently did not know of the latent resources of the Lake basin, nor the relative economies of water transportation—and even at the present time there is much misunderstanding as to the effect upon our industrial growth due to increased facilities.

It is well known that transportation seeks the line of least resistance (as measured by the total cost from mine to market). Tolls, transfer and terminal charges are as much an element of diversion as are physical obstacles. The Carnegie Company is now making efforts to ship direct from Lake ports *via* the Welland and St. Lawrence

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* Ex. Doc. No. 19. Thirtieth Congress. H. of Rep., First Session, Jan. 12th, 1848.

Mr. Haupt. Canals, after making the overland portage by rail. Were the Lake Erie and Ohio River Ship Canal opened it would not only greatly facilitate this movement, but it would also augment the coal tonnage to Eastern Atlantic ports, and hence it would seem to be unwise not to make provision in the dimensions of the canal for not less than between 15 000 000 and 20 000 000 cargo-tons soon after its opening to tidewater. There is, no doubt, much truth in the contention of Major Symons, that if the freight once reached Lake Ontario it would not lock up over a high divide and longer route to maintain the City of New York as a commercial terminus, but would be switched off *via* the Montreal route; but, at the same time, that would seem to be no reason for denying to the densely peopled manufacturing and productive agricultural districts tributary to the Lakes the advantages of lower rates and more extensive markets. New York City is not the United States, and if that city may not share in the benefits (which the writer does not admit would happen), other sections should not be debarred from such advantages.

It is said that "if built by the United States, the benefits should all accrue to the United States;" and, again, "its benefits should accrue only to the United States." The only route which permits this is that "along the line of the present Erie Canal," and hence the prism of lesser dimensions, with a barge system of carriers, is urged.

But can the beneficent influences of a canal or cheap water route be restricted to any country? Do not the waterways of France and Germany enable our exports and their imports to permeate every avenue of trade, and supply points not otherwise accessible at the same rates, to the benefit of our producers? If our shortest and cheapest route to our foreign markets lies through Canadian waters, is there any reason why our producers should not utilize them rather than pay for transfers and storage at both ends of a broken and circuitous route?

It should also be noted that the staple products of a State tributary to a deep water route are quoted higher than those at remote points and which require transhipments, so that the producer reaps the benefit of the cheaper route, while the consumer also buys at a lower price because of the economy in cost of carriage.

Money spent in the maintenance of an expensive system requiring, say, 60% of the gross income for operation when one is available which can be maintained and operated for one-half or one-third this cost, is extravagant. It has been estimated by Stevenson that the value of a commercial channel varies as the cube of the depth, while the economy of bulk movements is fully sustained by the rapid increase in the size of ocean freighters and the demand for deeper channels to carry them.

Many minor questions suggest themselves, as speed, ratio of beam dimension to section of canal trunk, number of trips per annum, cost

Mr. Haupt.

of plant for a given tonnage movement, etc., which have been more or less fully treated at the Navigation Congresses and by the members of this Society, so that it is not desirable to review them here, as the intention of the writer is merely to emphasize the need of making early provision for the largest movement, in view of the rapid increase of population and traffic in sight.

It does not appear to be appreciated that by the year 1930 our population will have almost doubled, and that we are increasing three times more rapidly than any of the civilized nations of the world whose statistics are available to the writer. Ordinary prudence would therefore demand that early provision be made to maintain our freedom of internal circulation, and the creation of external markets to provide employment for the next generation, and prevent degeneration and distress.

During the past century each decennial ratio has shown an average decrease of $\frac{19}{400}$ of the preceding ratio, yet the actual numerical increase of population has gone on in a geometrical ratio. The increase during the past decade, for example, was nearly 14 000 000, or more than the entire increase from the discovery of America to 1830, and between 1920 and 1930 the increase should be about 25 000 000 souls. Another factor which will augment greatly the commerce through the enlarged canal will be the opening of the link between Chicago and the Mississippi River, now being urged by the Illinois River Valley Association, thus bringing the waterways of the Great Basin into unison with those of the Lakes during the season of navigation. This is not so remote as was the Sault Canal in 1840, and it is one of the great and urgent improvements required by the present generation, and which will promote the future of our great Republic. Let the American Society of Civil Engineers be found in the forefront of all these great movements to develop our commerce.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

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PAPERS AND DISCUSSIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

A DIRECT METHOD OF SPACING RIVETS AND FINDING THE POSITION, ETC., OF STIFFENERS IN PLATE GIRDERS.

Discussion.*

BY J. W. SCHAUB, M. AM. SOC. C. E.

Mr. Schaub. J. W. SCHAUB, M. Am. Soc. C. E. (by letter).—The writer wishes to call attention to the author's method of proportioning the intermediate stiffeners to carry the shear on the web of a girder. This is the usual method of proportioning for stiffeners, but it can be shown that, if, in some way, the load can be put into the web, no stiffeners whatever will be required, except, of course, the end stiffeners. This is contrary to all accepted theories of web stresses, but a little experiment can be made to demonstrate it.

The following experiment was made by the writer† before the Western Society of Engineers, October 10th, 1900:

Make a plate-girder model of drawing paper, about 15 ins. long and 3 ins. deep, with two flange angles at the top and bottom, and let the web of the girder project below the bottom flange angles, so that the loads can be suspended by means of hangers attached to the projecting web. Now support the girder at the ends and support the top

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* This discussion (of the paper by E. Schmitt, Assoc. M. Am. Soc. C. E., printed in *Proceedings* for November, 1900) is printed in *Proceedings* in order that the views expressed may be brought before all members of the Society for further discussion.

Communications on this subject received prior to January 26th, 1901, will be printed in a later number of *Proceedings*, and subsequently the whole discussion will be published in *Transactions*.

† "Proposed Specifications for Steel Railroad Bridges," *Journal*, Western Society of Engineers, October, 1900.

Mr. Schaub.

flange against crippling sideways. It will be found that loads which can be suspended from the hangers with perfect safety cannot be placed on top of the girder without buckling the web. Moreover, the web will stiffen up at once, and it will be found that, although the web is already carrying the suspended loads, additional loads can now be placed on top of the girder and the web will not buckle. It follows, then, that after the load is put into the web, the web is actually stiffer than it was before; so that stiffeners need only be provided to get the load into the web, and not to carry the maximum shear at any point. Would it not be more rational, then, to proportion the intermediate stiffeners to carry only the maximum concentrated load at any point, rather than the maximum shear?

With this experiment in view, the writer has specified, in a specification just issued for a western railroad, as follows:

> "Intermediate stiffeners shall be provided for, as struts carrying the maximum concentrated load at any point, including impact, whenever the clear width between flanges exceeds 50 times the thickness of the web, and they shall be spaced at intervals of about the depth of the girder. End stiffeners shall be provided to carry the maximum end shear, including impact."

This method is certainly very simple. For through plate-girders provision need be made for intermediate stiffeners only to attach the floor system to the web, and between the floor beams, or panel points, no intermediate stiffeners are required, no matter how long the panels are, or how thin the web may be; whereas, by the usual method of proportioning, intermediate stiffeners are provided for through plate-girders, the same as for deck plate girders. This leads frequently to some curious results. The writer has in mind a specification for a prominent southern road which required intermediate stiffeners, by a so-called stiffener formula, to be spaced at 2-ft. centers near the ends, and a number of through plate-girders were built accordingly, and are probably still being built according to this specification.

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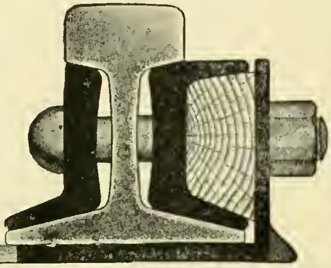

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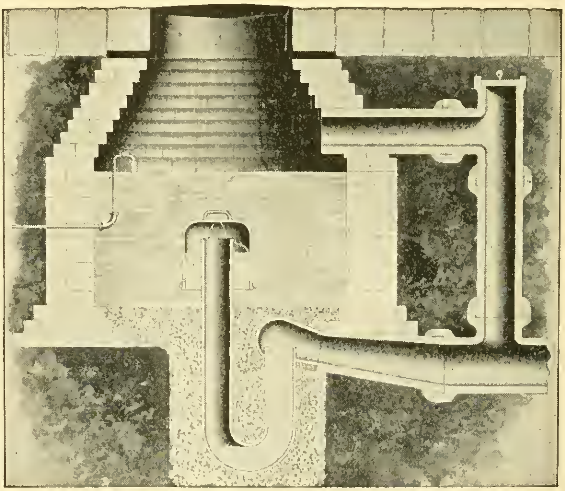

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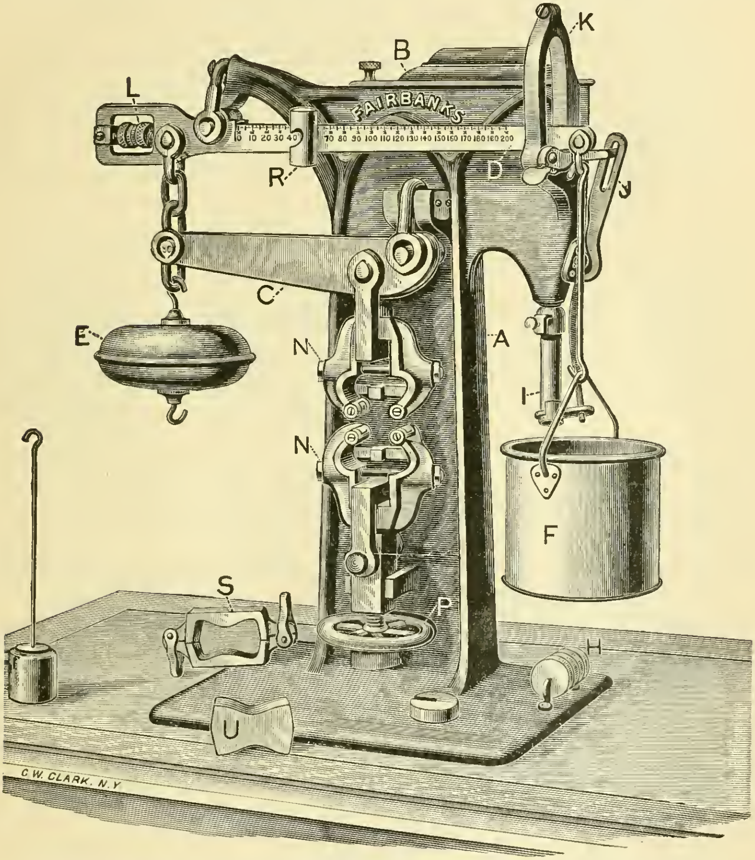

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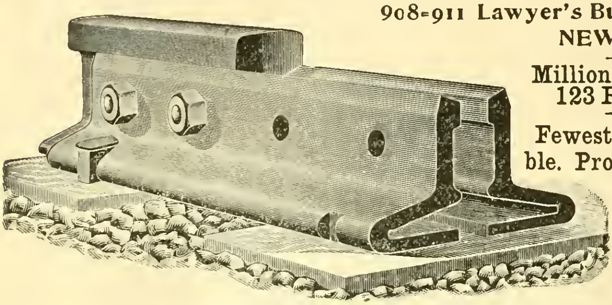

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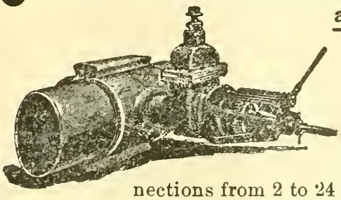

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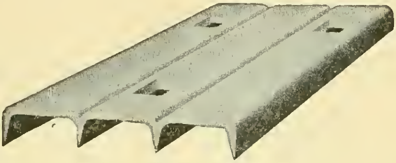

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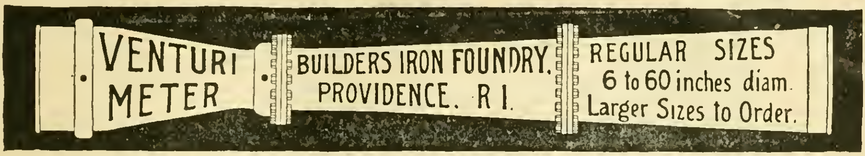
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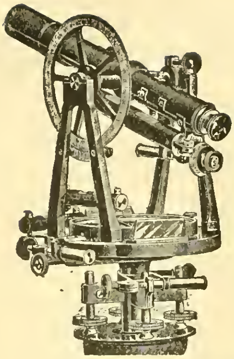

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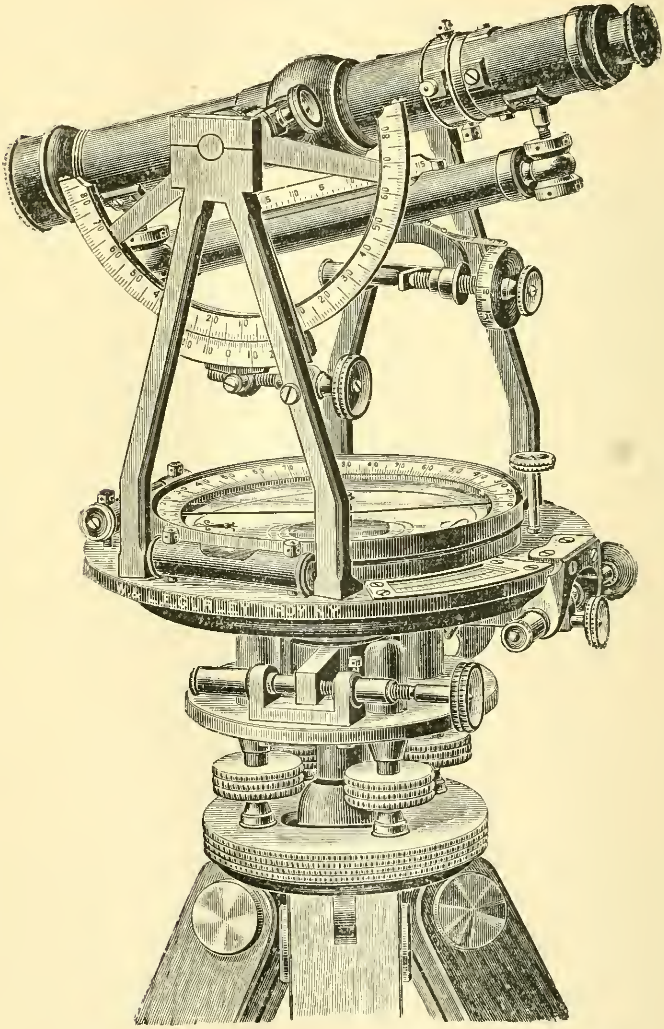
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